Valutazione delle condizioni anemologiche del territorio

(Exploring the wind climate of Cilento) by Duncan Heathfield

Introduction

This report describes some investigative work carried out in 2006 by Duncan Heathfield of World in a Box Finland OY, on behalf of the Dipartimento ARBOPAVE of the University of Napoli Federico II.

The purpose was to explore the application of the WAsP wind modelling software to the fire-wind climate of the Parco Nazionale del Cilento e Vallo di Diano. By “fire-wind climate”, I mean those aspects of the wind climate relevant to the understanding and management of wild fires.

Given the limitation of available data, there are no concrete or applicable results arising from the work, but this should be regarded as a ‘waypoint’ report, summarising the early stages of a longer investigation.

Wildfire and winds – what do we want to know?

Fire and wind

Fires start, get established, spread and eventually die out. The probability of a fire starting is a quite separate from the question of what happens once it starts.

The most significant factor in ignition risk is anthropogenic: where are the people and what are they doing. Weather (dryness) is also very important, and wind speed is an indirectly contributing factor to this, but wind direction is not relevant.

Winds are primarily of interest when considering the spread of fire: which way, and how fast, a fire will spread. The natural spread pattern is determined by the terrain slopes, the fuel type, fuel abundance and the wind. In the path of the spreading fire, the topography and fuel conditions will vary spatially, but - except in the case of precipitation - will not change dramatically from hour to hour, or even day to day. For wind it’s a different matter. As a fire burns, wind speed and direction can vary over space and time. There are interactions among all four factors, and the complex combination makes for a challenging simulation task.

For example, if the upper-air wind veers by only a few degrees, it might significantly change the direction and speed of the wind at the fire height, due to the effect of the topography. The change in direction may in turn influence the speed and turbulent properties of the wind at the fire because of a change in the roughness of the surface over which the wind arrives.

We have good models of wind behaviour, and good tools to characterise the temporal variation of the wind. How could we best use those tools to help us understand wildfire?

What do we want to know?

Let us consider who cares about understanding the effect of wind on the pattern of a fire's spread, and why. This will guide our investigation.

Fire simulation tools

While a fire is burning, anyone trying to control or extinguish it needs a mental model of its likely behaviour. If the fire speed increases, or the fire front direction changes, then unlucky fire-fighting personnel may be caught by surprise and exposed to great danger. People are killed by such surprises. Fire behaviour simulation tools supplied for real-time support of fire-fighting operations should take proper account of the wind and its variability. This might be provided in several ways:

- Statistical analysis of previous wind history to predict the relative likelihood of a given wind changing, and how. For example: 'In June, if the wind is more than 3m/s from the North at midday, then there's a 30% chance it will veer easterly by nightfall: : here's a map of the local wind conditions that would follow.'
- A received forecast change in the upper air wind conditions being applied to local conditions. For example: 'The regional prediction is for the wind to strengthen to 15m/s in by midday: here's a map of the local wind conditions that would arise.'
- Predictions of spatial pattern of wind conditions arising from a particular change suggested by the fire commander. For example: 'If, as you suggest, the wind speed drops by 25%, this is the map of local wind conditions that would then obtain in your area.'
- Reverse-prediction, to say what general changes would be necessary to cause a particular change in local conditions. For example: 'In order for the wind in that valley to change direction so as to run mostly up-valley instead of over the side (a 15 degree shift), the upper air wind direction would need to veer by 50 degrees to the South.'

Fire management planning

When fires aren't burning, the preparations for managing and controlling them must also be well-informed by models that take account of the wind climate.

The efficacy of a firebreak of course depends on its running more-or-less perpendicular to the direction of a fire's spread. Fire-fighting resources should sensibly be concentrated where there is a reasonable chance of halting a fire's spread: where it's likely to be advancing more slowly, and where firebrands are not being blown overhead, rendering futile any local successes in controlling or slowing the fire.

Again, there are several ways in which knowledge of the wind climate and its local effect could be usefully provided:

- Maps showing local wind speed and direction for certain weather conditions could be provided, for use in planning the layout of firebreaks and roads.
- Analysis of long-term meteorological data could indicate the wind conditions most associated with fire risk.

About the WAsP software

The WAsP software is produced by the Wind Energy Department of the Risoe National Laboratory in Denmark. The software consists of various programs, of which three are of interest here:-

1. WAsP
2. WAsP Engineering (WEng)
3. The WAsP Climate Analyst (WaCA)

WAsP is a rather contrived acronym, standing for Wind Atlas Analysis and Application Program. The software's fundamental raison d'être is to serve the needs of consultants planning the installation of electricity-generating wind turbines around the world.

The WAsP program itself is mostly devoted to predicting the electrical output of a wind farm: it concentrates on the mean wind climate, characterised by the Weibull probability distribution of speeds. The WEng program helps to calculate what kind of turbine can safely be installed in a given location: it concentrates on extreme wind climate, characterised by the Gumbel probability distribution, and turbulence. The WaCA program is a time-series processing program which calculates mean and extreme wind climates from observed time series of meteorological data.

Despite being mainly designed for wind energy consultants, the programs have a wider range of possible applications. Both WAsP and WEng work by taking a wind observed in one place and predicting the simultaneous wind conditions obtaining in other places in the same landscape. Both programs do this in a completely different way, but the result is nevertheless logically equivalent. A particularly relevant difference between the two program arises from the fact that WAsP works only with wind climates (for example, by applying site 'corrections' to a Weibull distribution), whereas WEng works with particular wind conditions (for example by predicting the turbulence at a site given a geostrophic wind of such-and-such a speed and direction). It's possible to 'trick' WAsP to work with particular wind conditions, but for WEng, this is the normal mode of operation.

In WEng, one can set up a modelled situation (domain) with a map describing the orography (elevation) and surface roughness (roughness length). A wind (speed & direction) observed at a given place in the map (x,y,z) can be entered, and the program can predict the speed and direction of the wind at any other point in the domain. The program can of course do many other things too, but this essential predictive capacity is the function most relevant to landscape ecological modelling. It has a wide range of possible applications, from predicting snow depth, forest storm damage and (as we explore in this document), the simulation of the spread of wild fires.

The meteorological stations

We worked with time-series data from four meteorological stations around the park. The map below shows their locations.

This is a semi-opaque overlay view in Google Earth, showing the park's extent (grey) as retrieved from the Cilento park web site.

The stations at Policastro, Buonabitacolo and Agropoli are operated by the Centro Agrometeorologico Regionale of Regione Campania. The data from the Capo Palinuro site were just used as a background reference about the long-term wind climate.

Here are the stations' locations.

Site	Address	Lat, Long (WGS84)	UTM33T ED50	Altitude (a.s.l.)	Height (a.g.l.)
Policastro	Policastro Bussentino, via Orto del Conte	40°04'35'' N, 15°31'57'' E	545475, 443662	10 m	10 m
Buonabitacolo	Buonabitacolo, Loc. Tempa del Mulino	40°17’30” N, 15°38’04’’ E	553903, 4470511	475 m	10 m
Agropoli	Agropoli, Contr. Mattine	40°22'51'' N, 15°02'06'' E	503043, 4470217	20 m	10 m
Capo Palinuro	-	40°01'12'' N, 15°16'48'' E	-	185 m	24 m

The meteorological data

From Capo Palinuro, there's a long-term data set describing only wind speed and direction. There are three-hourly records from 1951-01-03 to 1970-10-30. These data have been used to calculate the regional mean wind climate (Wind Atlas), which is cleaned of local site effects. For this investigation, the data and the atlas were used only to provide a long-term background reference against which to compare the shorter data sets available from the other sites.

From each of the three sites Policastro, Buonabitacolo and Agropoli, there were two data sets: daily measurements from 1999-2005 and some three-hourly data from 2003-2005.

Three-hourly data

Each set has about eight readings per day with the following fields:

- Date
- Time
- Average air temperature
- Average ground temperature
- Solar radiation
- Wind speed
- Wind direction

There are a few missing records, and a few extra ones, but generally the data appear to be consistent and complete. The data sets' durations are as follows:

Site	Start date	End date
Agropoli	2003-01-01	2005-06-21
Buonabitacolo	2003-01-01	2006-01-01
Policastro	2003-01-01	2006-01-01

Daily data

Each set has the following fields:

- Date
- Max. temperature
- Min. temperature

- Mean temperature
- Max. humidity
- Min. humidity
- Mean humidity
- Precipitation
- Mean wind direction
- Mean wind speed
- Radiation

Site	Start date	End date	Notes
Agropoli	1999-01-01	2005-06-20	Lots of direction data missing 2000-04 to 2001-01
Buonabitacolo	1999-01-18	2005-12-31	Lots of data missing from 2000-06 to 2001-02.
Policastro	1999-01-01	2005-12-31	-

Some remarks about the limitations of the data

For some reason the Agropoli campaign was terminated in the middle 2005, which is disappointing because it thereby excludes the main 2005 fire season.

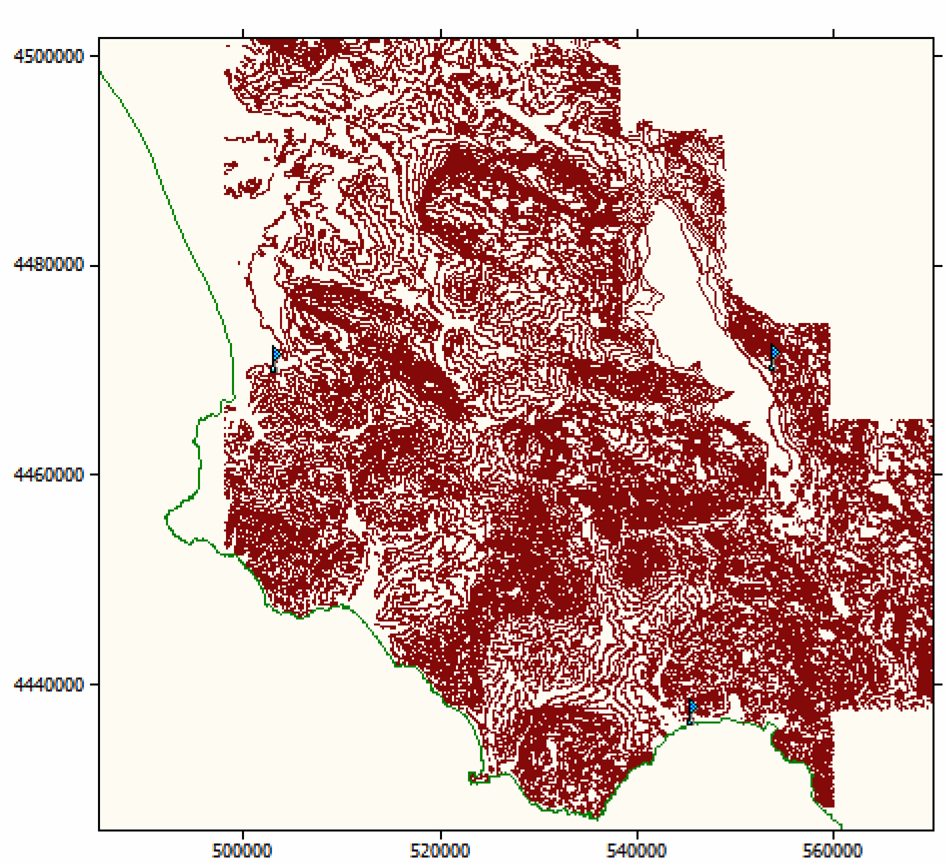
For wind climate analysis in the WAsP software, the standard for time-series data is that they should be averaged and recorded every ten minutes. It's possible to estimate the mean wind climate from three-hourly data, but the analysis and extrapolation of extreme winds via a Gumbel distribution is only valid using 10 minute averages.

Daily average wind speeds are perhaps useful for ecological and agricultural processes (which include calculating cumulative dryness for fire). However, except in some peculiar climates, daily wind direction readings are more-or-less meaningless. A possible exception is a direction reading taken at a particular time which is for some reason relevant. It seems from these data, though, that the daily direction is some kind of 24 hour average measure.

Another minor problem with the data is that there is no information about the instruments. For example, we don't know the calm threshold for the measurements. In fact it was possible to estimate it, and in any case it's not particularly relevant to this investigation. Nor do we know how the recorded wind data were calculated: for example, are the three-hour wind speeds averaged over three hours, or are they ten-minute averages recorded every three hours?

Spatial information

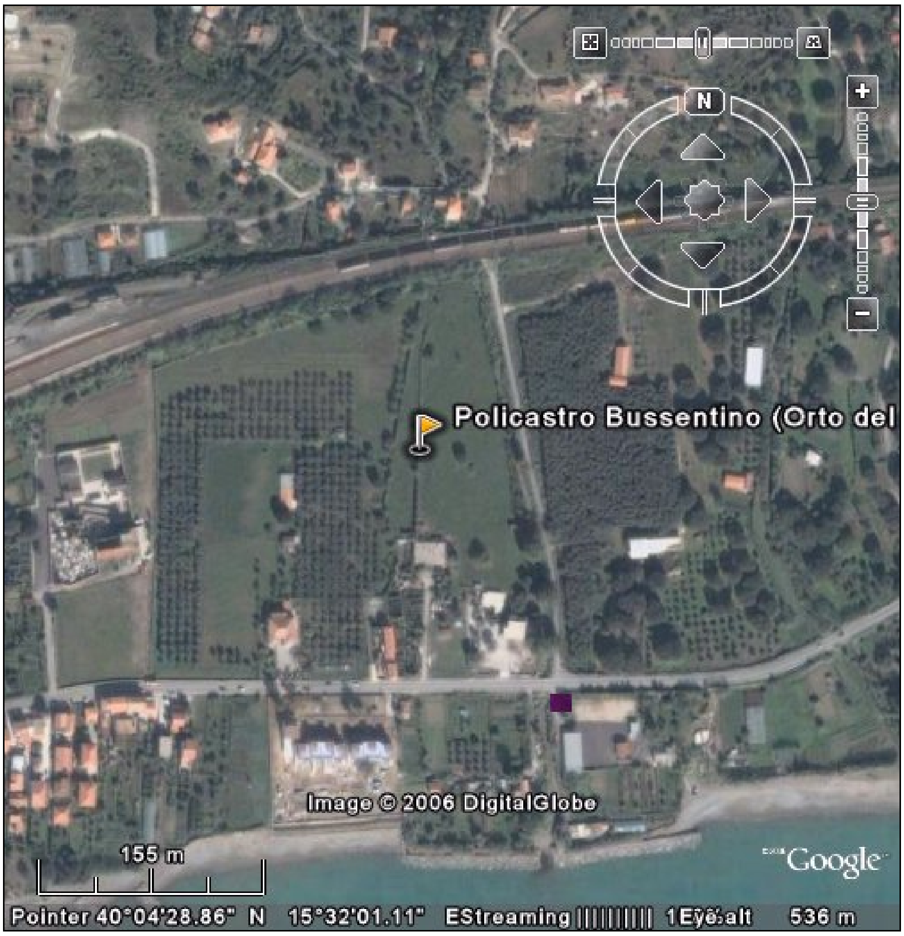
We were provided with a map describing the elevation of the area covered by the park. We were able to add a coastline to the map, and convert it for use in the WAsP Engineering software.



In addition, we were given a map and key of the various vegetation/land use types over the area, but at the time of writing it's not so far been possible to convert this for use with WAsP. This means that the wind fields predicted by WAsP software from our maps are unaffected by surface roughness, except for the land/sea transition. The actual wind field would be greatly affected by the roughness, and the WAsP models do much work to take proper account of it, so this is a significant omission.

The approximate metric co-ordinates of the meteorological stations are known from their latitude and longitude, but we have no detailed information about the sites themselves and their surroundings (obstacles, etc). We couldn't make out the sites' exact locations on satellite images from Google Maps, so were unable to create the data ourselves.

For example, using the satellite image shown below for the Policastro site, we would be able to use tools from inside WAsP to characterise the local roughness and obstacles.



It's clear, however, that it's necessary to know the location to within 20 metres or so: otherwise the information added would risk make the representation less accurate than with none.

This lack of site information limits our ability to 'clean' the data observed at the different meteorological stations, removing the effects of the particular site effects, and getting an idea of the background wind obtaining coincident with an measured wind observed at a given moment.

Which winds to model?

The WAsP software is capable of various different kinds of wind modelling task. Which are of interest? We're not interested in strong winds in themselves, nor are we interested in the mean annual wind energy content.

In the EUFireLab paper D-08-05 "Common methods for mapping the wildland fire danger" the authors write…

> Under non-extreme weather conditions, European Wildland Firefighting Agencies are very successful in suppressing wildland fires (VÉLEZ 2000, CASTELLNOU et al. 2001). This is not true regarding extreme weather conditions.

(In an adjacent passage, they identify the important weather conditions as temperature, relative humidity and wind speed.)

If we're interested in the 'problem' conditions, we need to model the winds which coincide with the most severe risk of fire spread.

The most obvious useful output from WAsP would perhaps be maps of local wind speed and direction associated with the fire conditions which the fire-fighters have most reason to fear. To identify these winds, we need to examine the weather history and compare the high-risk times with the corresponding wind conditions. I chose to use the Italian Fire Danger Index as a way of assessing the fire spread risk for each day.

The Italian Fire Danger index

The Italian Fire Danger Index (IFDI) is used for the Mediterranean part of Italy by the Italian State Forestry Corps. I found two references, each of which described the calculation procedure in identical terms.

One was the EUFireLab paper D-08-05 "Common methods for mapping the wildland fire danger". In this, the IFDI is mentioned in on page 60 and defined on pp 26-31.

The other was from the JRC. It runs a web server showing Europe-area maps of various risk indices at http://effis.jrc.it/wmi/viewer.html. The IFDI is one of the indices, and the web site has a paper explaining the calculation, at http://effis.jrc.it/documents/general-interest/Indices_description.pdf. The IFDI is explained on pages 13-19. It's the same text as in the EUFireLab paper.

The IFDI integrates several meteorological variables into an ongoing drought index, which is then combined with other variables to give a danger score.

Inputs (daily values):

- Maximum temperature
- Air temperature
- Precipitation
- Relative humidity
- Wind speed

Note that these input requirements are satisfied by the 1999-2005 daily data for the three sites described in the previous section.

I encountered several ambiguities in the documentation describing the calculation method, but was able to proceed by making reasonably straightforward assumptions about what was intended. I have carefully recorded the assumptions made (they are not presented here), so it will be easy in future to update the implementation if they are found to be incorrect.

Work with the time series data

What can be done with the data?

The daily data have all the meteorological information we need to calculate the Italian Fire Danger Index as a series of daily values. However, the index cannot be calculated from the three-hourly data. On the other hand, we cannot relate the danger index to wind direction for the daily data, because the daily mean direction is a more-or-less meaningless value. In the three-hourly data, we can use the direction information.

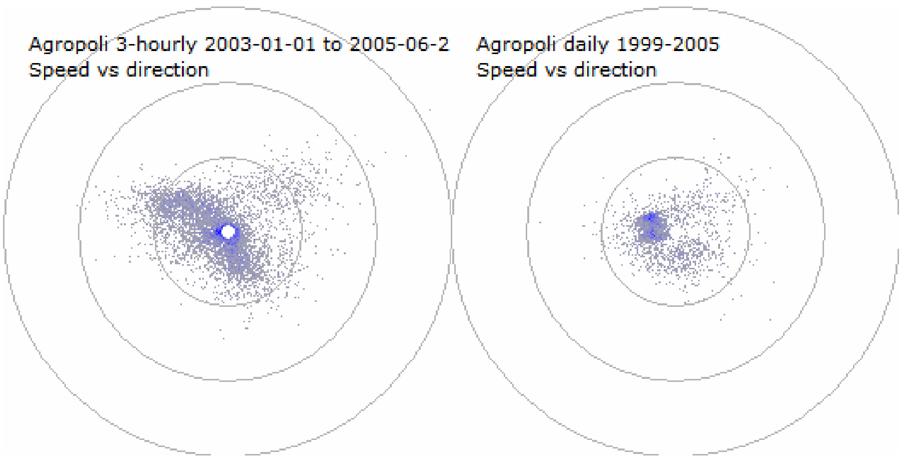
So, to understand the relationship between fire hazard and wind conditions, we need to use both data sets where they overlap. The overlap between them is only about three years (2003-2005), but that might be enough to get some insight into the fire risk conditions. The earlier daily data are useful to provide context for the fire risk values 2003-2005.

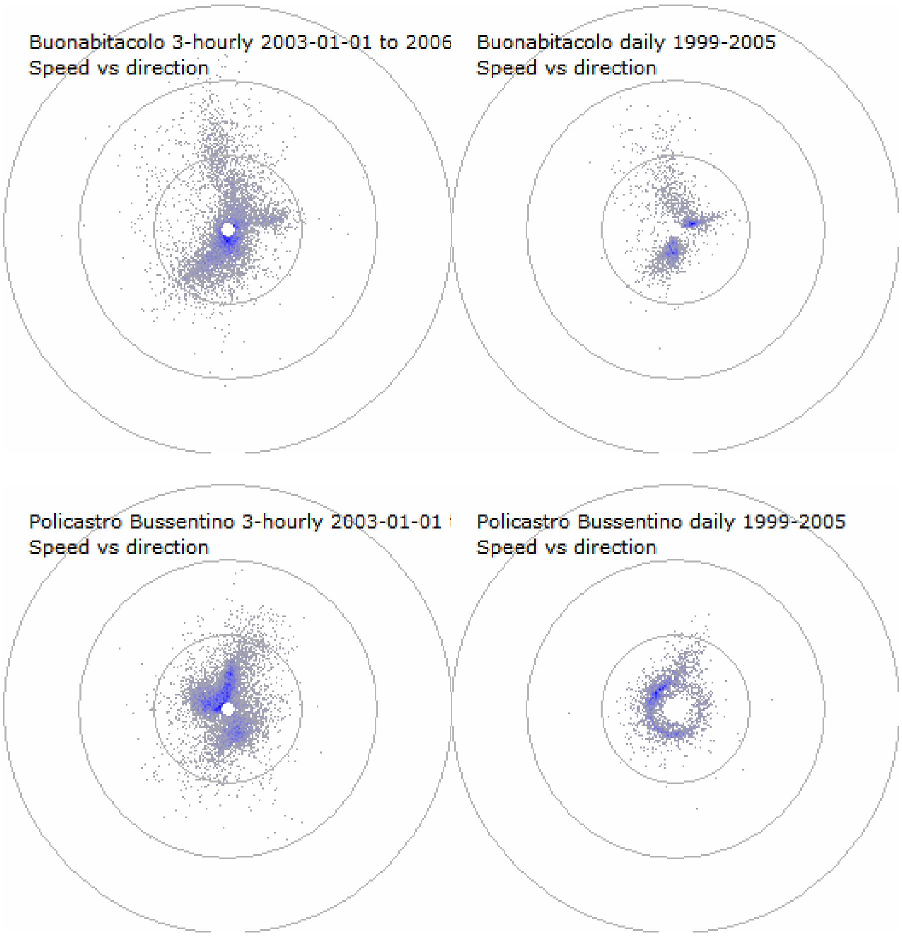
The Capo Palinuro data may be helpful in understanding whether the winds from 1999-2005 are representative of the long-term climate, but since they are collected at another location and we have no correlation data, we would need some spatial modelling work to apply them to the other sites for comparison.

Initial treatment and quick overview of the data

I wrote an ad-hoc program which reads all the data from Agropoli, Buonabitacolo and Policastro, and cleans them up and balances them, applies the calm threshold (estimated as 0.4 m/s) and inserts standard flag values where data are missing, and so on.

Here are some scatter plots showing the wind data from the sites. The speeds are shown using scaling rings at intervals of 5m/s. Colour intensity corresponds to frequency. Calms are not included in the plots. The calm threshold gives rise to the white centre circle in each plot.





Note that the daily data sets are showing a longer period of records than the 3-hourly ones.

Generally, it's clear that:

- The daily data exhibit less wind speed variation than the 3 hourly (that's entirely expected)
- The general pattern of directions match between the daily and three-hourly data
- Each site has its own distinct pattern of wind directions.

I also loaded the data (including the Capo Palinuro data) into the WAsP Climate Analyst program to explore them. I omit the detailed description and illustrations from this document, and summarise the results thus:

- The Policastro data sets (both daily and three-hourly) are apparently the most complete and reliable
- For all sites, the strongest winds seem to come from the north and south (as measured at the sites without terrain/obstacle corrections).
- The few years' wind data we have don't obviously disagree with the longer term wind data from Capo Palinuro.

Comparing the three-hourly and daily data sets for each site

There are only three matching data fields between the three-hourly and daily data sets: wind direction, wind speed and mean temperature. I'm assuming that the mean temperature in the daily data corresponds to the mean *air* temperature in the three-hourly data.

Temperature and speed match well

I wrote some code which calculated the mean temperature and speed for each day from the three-hourly data and compared it with the daily record from the daily data. For each day, the difference is calculated and then these differences arranged in a histogram.

For each site, for both temperature and speed, there is on most days a very small difference. The mean difference in speed and temperature is less than 0.1 m/s for all sites, and less than 0.4 degrees for all sites. We can say that the daily data correspond well with the three-hourly ones, and just represent the same information at a lower resolution.

Direction is a different story

As I hinted above, the "daily direction" is difficult to interpret. I analysed the three-hourly data for the volatility of direction. The average change from one three-hourly period to the next was about 57 degrees. (A completely random fluctuation would yield 90 degrees.) It's hard to imagine a daily value capturing any meaningful summary description of the days' wind directions.

This leads us to expect that there would be little relationship between the daily and the three hourly values. Indeed the relationship is very weak. For each three-hourly record, I calculated the difference between the recorded direction and the daily direction figure from the same day. The mean differences for the three sites were 42, 49 and 61 degrees. Again, 90 would be produced by random data.

It was possible that the daily values corresponded to one of the three hourly intervals (midday for example), so I then compared the direction for each three-hourly time against the corresponding day value. The following results emerged:

Day parts direction discrepancy from whole day

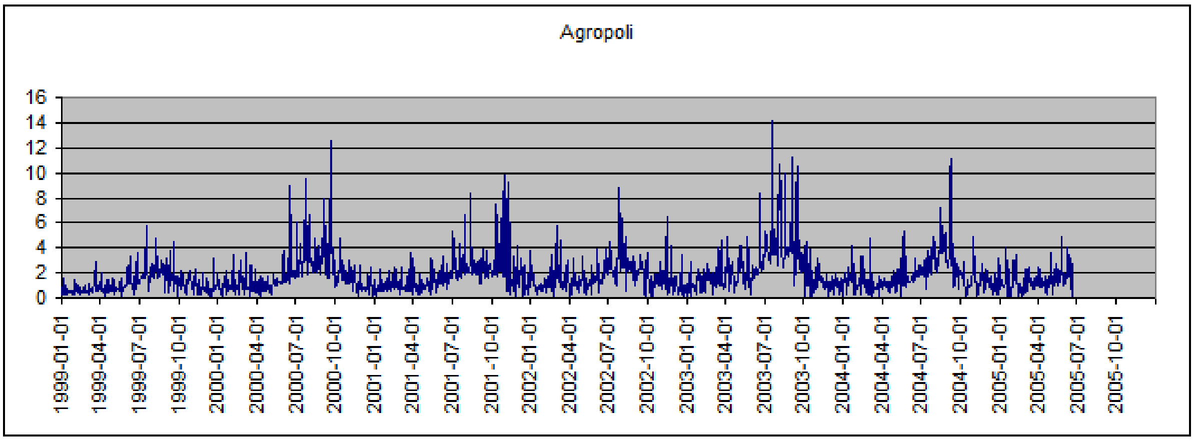
Hour	Mean disc. from daily value		
	Agropoli	Buonabitacolo	Policastro
00:00	73°	54°	67°
03:00	70°	53°	60°
06:00	63°	55°	59°
09:00	48°	55°	46°
12:00	32°	36°	68°
15:00	28°	26°	66°
18:00	38°	37°	54°
21:00	70°	52°	75°

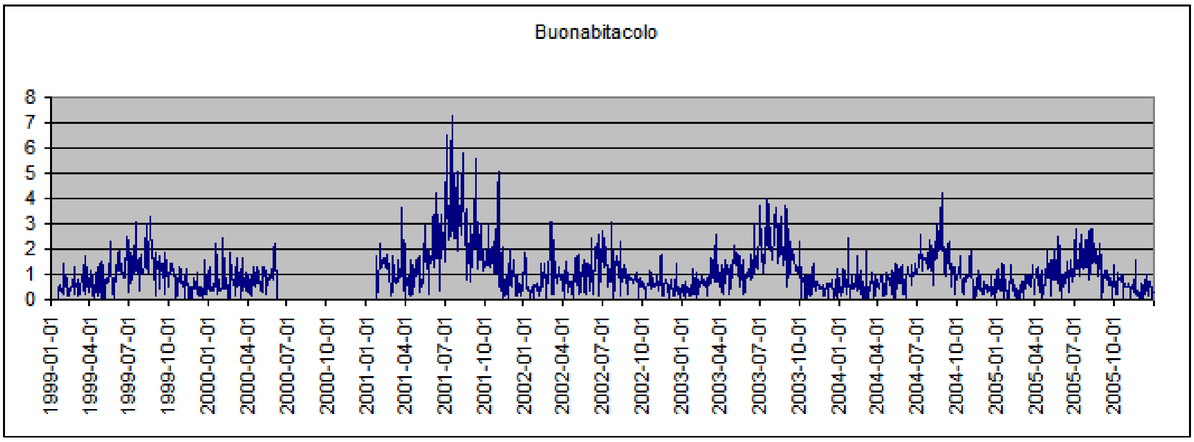
Generally, there's no correspondence. The match is slightly better for afternoon readings, but those are bad too. I decided that - in general - the daily direction data are meaningless. However, it’s possible that for the days which we are particularly interested in for fire, the wind direction is not volatile.

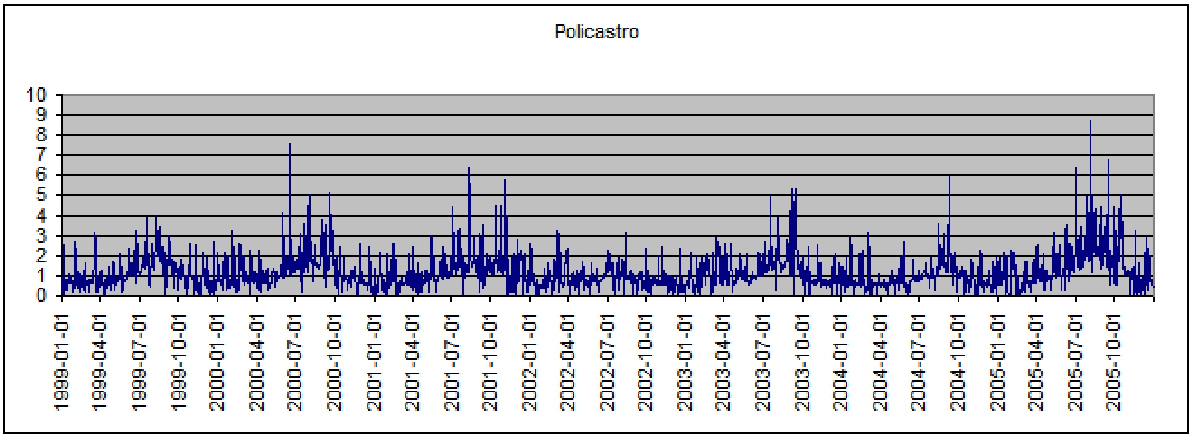
Fire danger index calculations

From the daily data

I calculated the daily Italian Fire Danger Index value for each site using the daily data sets (mean wind speed). Here are some simple time series plots from Excel to illustrate the range of values and annual patterns.



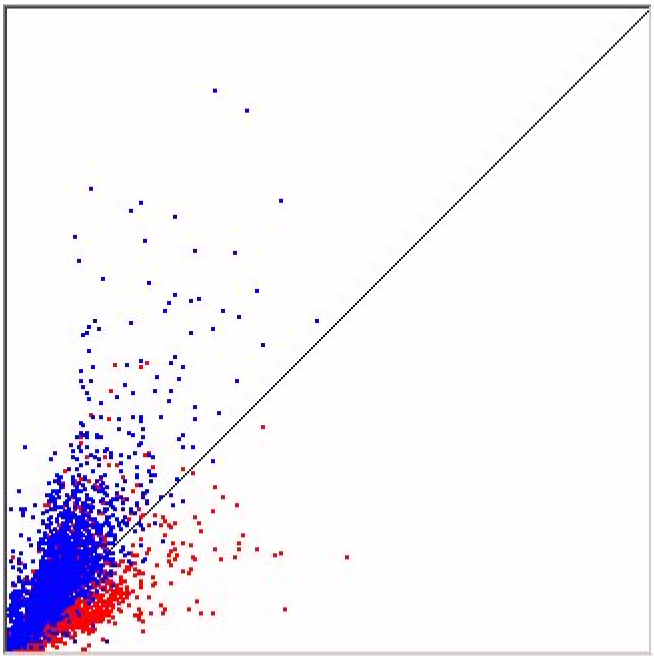




Note that the gap in the Buonabitacolo data in 2000 coincides with periods of high fire danger for the other two sites. What's more, the termination of the Agropoli campaign immediately precedes a very high-danger summer according to the Policastro readings.

There's a clear annual pattern, of course. But it's also clear that there are strong differences among the three sites. Is it the case that the three sites all share the same background fire-risk climate, with a different manifestation according to the site conditions?

The following plot shows the daily danger indices for Buonabitacolo (red) and Agropoli (blue) plotted against the corresponding values for Policastro. These indices have been recalculated so as all to use the same wind speed (10km/hr), and so should represent the relative non-wind meteorological danger.

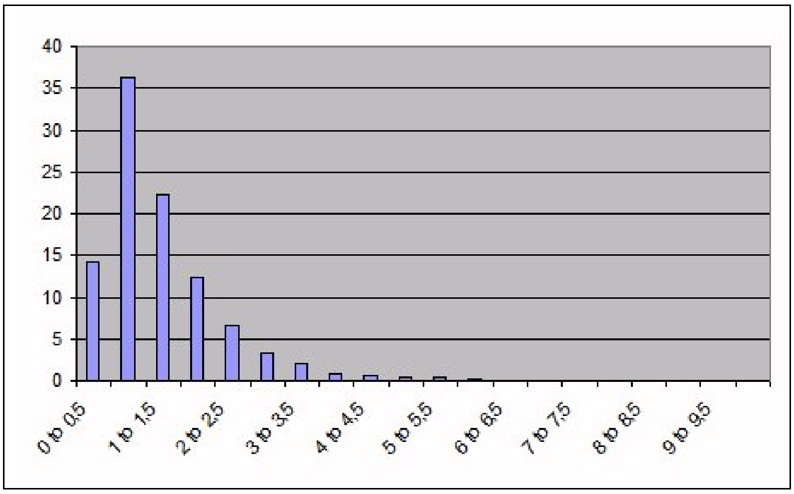


It's clear that there is some broad correlation, but that the highest danger days don't necessarily coincide for different sites. Perhaps we shouldn't expect them to: a local rain shower can disrupt the pattern. On the other hand, maybe there is no justification for seeking some aggregated measure of fire risk over all three sites: perhaps each site has its own fire danger climate. This points to an unwelcome complication. We have no immediately obvious way of working out the relationship between these sites' weather and the conditions at other, arbitrary points in the park.

I made a visual inspection of the by-danger top ranked dates for each site and noticed that the Agropoli and Policastro data seemed to agree much of the time about which days were risky, but the missing parts of the different data series make it difficult to compare.

The fire danger frequency distributions

The probability distribution of different danger index values is strongly skewed to low values. For example, here's a plot showing the distribution of daily FDI values for Policastro (1999-2005). The danger index values are shown along the bottom axis, and the percentage frequency is shown on the vertical axis.



The mean value is 1,22. The median is 0,96. Only one percent of the days have values exceeding 4,4.

Danger and wind direction

The daily direction data are not reliable. To examine the possible relationship between danger and wind direction, we are restricted to using the periods of overlap between the two data sets, which are as follows:

Site	**Start**	**End**
Agropoli	2003-01-01	2005-06-21
Buonabitacolo	2003-01-01	2005-12-31
Policastro	2003-01-01	2005-12-31

Three-hourly danger values

To calculate the three-hourly danger, I took the non-wind parameters from the overlapping part of the daily data series, and calculated the danger index using the three-hourly wind speed. The three-hourly data also contain mean temperatures, but I chose to use the daily ones because it seems to fit more comfortably with design of the index.

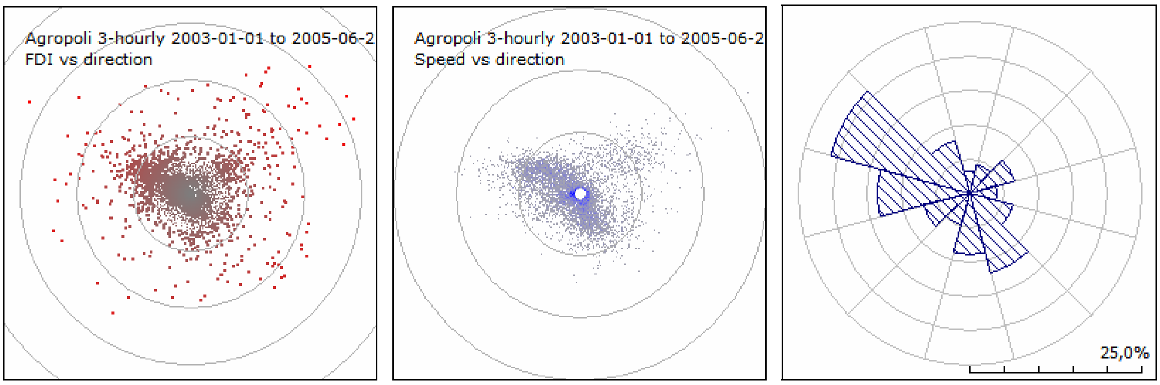
I don't show here the time-series of three-hourly danger values, nor do I illustrate their probability distributions. Suffice to say that the patterns were similar. For Policastro, for example:

	Daily FDI	Three-hourly FDI
N	2500	8700
Mean	1,22	1,22
Median	0,96	0,98
99% of data less than	4,4	4,7

Each of the plots below show (in red) the dangers calculated for three-hourly data, next to each is the corresponding speed scatter plot and below each is the corresponding mean wind frequency rose calculated by the WAsP Climate Analyst. Note that the radial scales for the three plots are in no way equivalent: they are showing entirely different phenomena. The red dots are scaled by fire danger. The blue-grey dots are by speed, and the filled area rose is by sector-wise frequency.

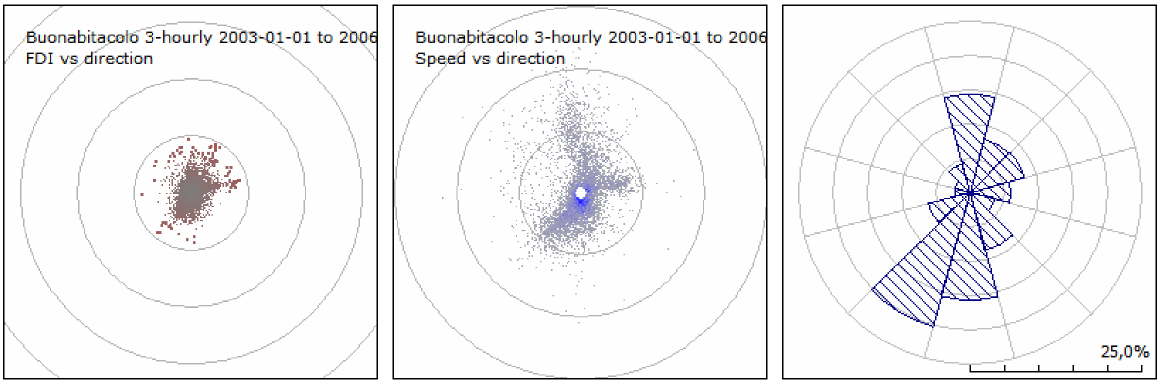
The plots for Agropoli

Remember that the Agropoli data omit most of the 2005 fire season, so the high danger values arise from only two summers.



Most noticeable here is the apparently random scatter of danger. The danger plot shows significant departures from the other two. It points to the fact that relying on some simple idea of 'the prevailing wind' would be misleading with respect to fire planning. It's also (trivially) a clear indication that other factors than wind speed are having a significant effect on the calculation of danger, despite the fact that occasional strong winds from the north-west are apparently associated with high fire danger.

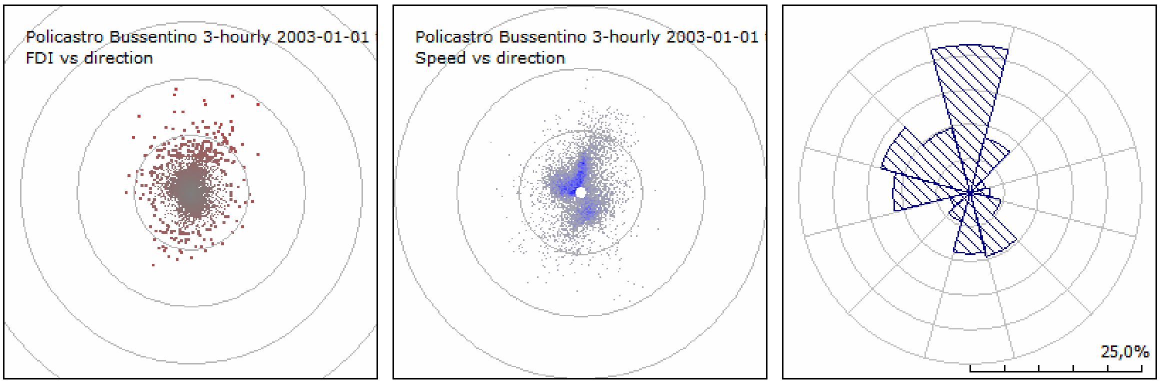
The plots for Buonabitacolo



The danger values are generally lower than from the other sites. This is probably explained by the higher elevation and lower temperatures.

As with the Agropoli data, the danger/direction relationship doesn't closely follow the frequency distribution.

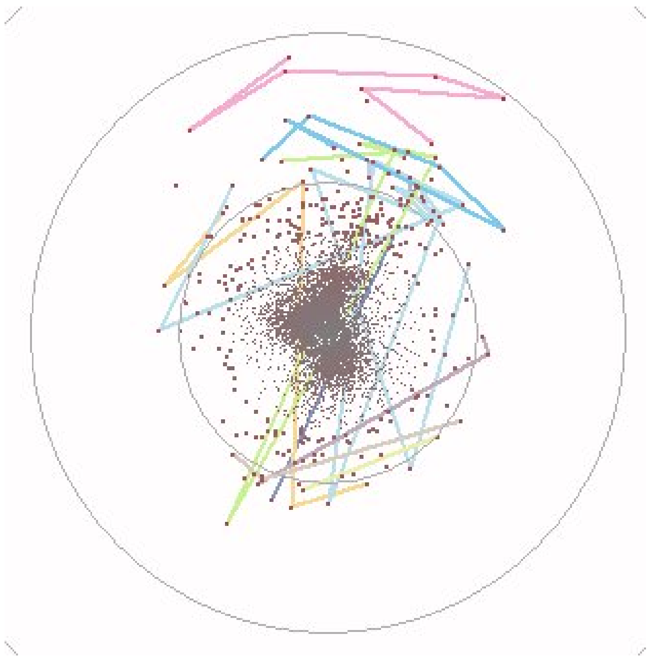
The plots for Policastro



Policastro shows an interesting feature: there is frequently wind from SSE, and these winds are sometimes strong, but they are clearly not associated with high fire danger.

Direction volatility and fire danger 'episodes'

What these danger plots don't indicate clearly is any temporal clustering of fire danger. I tweaked the plot drawing to show lines between high danger times. Here's the result for Policastro:



Each run of consecutive high-danger readings is joined together by a randomly coloured line.

The plot reveals that the three-hourly direction is quite volatile even within a period of high danger, with occasional big changes.

We must remember that the data a 'raw'- as observed, and have not been cleaned of site effects. Nevertheless, the volatility indicates that if we wanted to 'sectorise' the danger into direction bins, then we would need more data to justify the averaging, or a method of characterising the distribution of risks in each sector that allows some extrapolation (the development of which would in turn require some longer time series in the first instance).

In the absence of such a long-term data, we might be better off examining short chunks of time associated with high danger values (danger 'episodes), and making a manual attempt to understand the wind conditions for the duration of the episode.

Using a ranked sort to discover episodes

The best approach is probably to rank the readings according to the fire danger, and see what the most dangerous conditions look like. I first tried naively sorting by the daily fire danger and looking at the top few days, but then noticed that would not necessarily agree with idea which arose from looking at the zig-zag scatter plot presented above. The actual calendar day divides the time too arbitrarily into 24 hour chunks, whereas we are actually interested in the short sequences of high danger, regardless of date.

I calculated a running 12-hour average of fire danger, and ranked the data by that. Here, for Policastro, are the top 25 lines.

3 hour timestamp	Day speed	Hour speed	Day danger	Hour danger	Rolling average 12 hours
2005-08-05 15:00	3,9	5,4	8,7	9,8	9,0
2005-08-05 18:00	3,9	3,2	8,7	8,2	9,0
2005-08-05 12:00	3,9	4,7	8,7	9,3	8,9
2005-08-05 21:00	3,9	1,7	8,7	7,3	8,6
2005-08-05 09:00	3,9	4,1	8,7	8,8	8,6
2005-08-06 00:00	2,4	1,5	4,8	4,5	7,4
2005-08-05 06:00	3,9	3,2	8,7	8,2	7,1
2005-09-15 15:00	3,3	4,1	6,8	7,3	7,0
2005-07-03 15:00	3,0	3,9	6,4	6,9	6,8
2005-09-15 09:00	3,3	3,1	6,8	6,7	6,8
2005-09-15 21:00	3,3		6,8		6,8
2005-07-03 18:00	3,0	3,0	6,4	6,4	6,8
2005-09-15 12:00	3,3	3,4	6,8	6,8	6,7
2005-09-15 18:00	3,3	2,2	6,8	6,2	6,7
2005-07-03 21:00	3,0	3,0	6,4	6,4	6,7
2005-07-03 12:00	3,0	4,4	6,4	7,2	6,6
2005-07-03 09:00	3,0	3,3	6,4	6,6	6,2
2005-08-06 03:00	2,4	1,6	4,8	4,5	6,1
2004-09-09 12:00	1,8	1,9	5,9	6,0	5,9
2004-09-09 09:00	1,8	2,5	5,9	6,3	5,9
2004-09-09 15:00	1,8	1,3	5,9	5,7	5,9

2004-09-09 18:00	1,8	0,8	5,9	5,4	5,8
2004-09-09 06:00	1,8	1,3	5,9	5,7	5,8
2005-07-04 00:00	2,5	1,5	3,7	3,4	5,8
2004-09-09 21:00	1,8	1,4	5,9	5,7	5,7
2005-09-16 00:00	2,0	2,1	3,5	3,5	5,7
2005-08-05 03:00	3,9	4,7	8,7	9,3	5,6
2003-09-05 12:00	2,5	3,9	5,3	5,9	5,5

These, and most of the next 75 readings, point to the following set of 'episodes'

- 2003-07-19
- 2003-09-05
- 2003-09-16
- 2004-09-09,10
- 2005-07-03,04
- 2005-08-05,06
- 2005-09-15,16

The following table shows the time sequence for each of these episodes:

3 hour timestamp	Hour speed	Day dir	Hour dir	Hour T	Hour danger
2003-07-19 00:00	1,6	35,0	349,0	23,3	4,4
2003-07-19 03:00	1,0	35,0	23,0	22,4	4,2
2003-07-19 06:00	1,0	35,0	269,0	25,5	4,2
2003-07-19 09:00	5,8	35,0	34,0	31,7	6,2
2003-07-19 12:00	4,8	35,0	31,0	34,6	5,7
2003-07-19 15:00	5,0	35,0	199,0	32,2	5,8
2003-07-19 18:00	1,3	35,0	219,0	30,1	4,3
2003-07-19 21:00	3,4	35,0	29,0	28,7	5,1
2003-09-04 21:00	2,0	19,0	340,0	20,9	2,7
2003-09-05 00:00	2,2	275,0	309,0	19,9	5,2
2003-09-05 03:00	2,6	275,0	319,0	17,4	5,3
2003-09-05 06:00	3,4	275,0	286,0	17,2	5,7
2003-09-05 09:00	2,2	275,0	351,0	24,1	5,2
2003-09-05 12:00	3,9	275,0	192,0	25,4	5,9
2003-09-05 15:00	2,3	275,0	165,0	26,3	5,2
2003-09-05 18:00	1,3	275,0	76,0	23,8	4,8
2003-09-05 21:00	1,2	275,0	295,0	18,5	4,8
2003-09-06 00:00	0,6	291,0	269,0	16,2	2,4

2003-09-06 03:00	1,4	291,0	305,0	17,4	2,5
2003-09-06 06:00	1,9	291,0	288,0	16,2	2,6
2003-09-06 09:00	2,5	291,0	252,0	21,8	2,8
2003-09-15 18:00	3,0	26,0	37,0	23,3	4,5
2003-09-15 21:00	2,5	26,0	23,0	21,4	4,3
2003-09-16 00:00	1,5	22,0	19,0	20,1	4,8
2003-09-16 03:00	3,7	22,0	21,0	20,4	5,7
2003-09-16 06:00	4,1	22,0	13,0	19,8	5,9
2003-09-16 09:00	2,9	22,0	15,0	24,1	5,4
2003-09-16 12:00	1,7	22,0	156,0	26,9	4,9
2003-09-16 15:00	2,3	22,0	191,0	26,5	5,1
2003-09-16 18:00	2,5	22,0	32,0	23,8	5,2
2003-09-16 21:00	4,1	22,0	28,0	21,9	5,9
2003-09-17 00:00	4,3	307,0	19,0	20,6	3,5
2003-09-17 03:00	2,2	307,0	349,0	19,4	2,9
2003-09-17 06:00	1,6	307,0	282,0	17,5	2,8
2004-09-09 00:00	1,8	20,0	24,0	22,2	5,9
2004-09-09 03:00	1,7	20,0	327,0	21,1	5,9
2004-09-09 06:00	1,3	20,0	271,0	18,8	5,7
2004-09-09 09:00	2,5	20,0	47,0	25,7	6,3
2004-09-09 12:00	1,9	20,0	15,0	29,8	6,0
2004-09-09 15:00	1,3	20,0	180,0	30,4	5,7
2004-09-09 18:00	0,8	20,0	44,0	24,5	5,4
2004-09-09 21:00	1,4	20,0	32,0	23,5	5,7
2004-09-10 00:00	1,3	17,0	43,0	21,0	5,2
2004-09-10 03:00	1,7	17,0	24,0	20,4	5,3
2004-09-10 06:00	1,9	17,0	32,0	20,4	5,4
2004-09-10 09:00	1,7	17,0	47,0	24,9	5,3
2004-09-10 12:00	2,1	17,0	354,0	28,7	5,5
2004-09-10 15:00	1,5	17,0	148,0	28,2	5,3
2004-09-10 18:00	1,5	17,0	64,0	24,5	5,3
2004-09-10 21:00	0,8	17,0	271,0	17,3	5,0
2004-09-11 00:00	1,7	288,0	292,0	19,3	2,9
2005-07-02 09:00	1,8	83,0	195,0	26,7	2,8
2005-07-02 12:00	2,8	83,0	191,0	28,3	3,1

2005-07-02 15:00	3,5	83,0	196,0	28,5	3,3
2005-07-02 18:00	1,1	83,0	190,0	27,9	2,7
2005-07-02 21:00	2,4	83,0	9,0	24,6	3,0
2005-07-03 00:00	1,9	22,0	5,0	23,4	5,8
2005-07-03 03:00	2,1	22,0	345,0	23,3	5,9
2005-07-03 06:00	3,5	22,0	24,0	24,2	6,7
2005-07-03 09:00	3,3	22,0	20,0	27,5	6,6
2005-07-03 12:00	4,4	22,0	208,0	28,0	7,2
2005-07-03 15:00	3,9	22,0	32,0	29,8	6,9
2005-07-03 18:00	3,0	22,0	10,0	29,3	6,4
2005-07-03 21:00	3,0	22,0	24,0	25,4	6,4
2005-07-04 00:00	1,5	70,0	52,0	22,8	3,4
2005-07-04 03:00	2,3	70,0	23,0	22,0	3,6
2005-07-04 06:00	3,7	70,0	24,0	23,9	4,1
2005-07-04 09:00	3,6	70,0	41,0	28,0	4,0
2005-07-04 12:00	4,3	70,0	200,0	27,5	4,3
2005-07-04 15:00	2,5	70,0	124,0	27,5	3,7
2005-07-04 18:00	1,3	70,0	148,0	25,6	3,3
2005-07-04 21:00	3,4	70,0	8,0	20,9	4,0
2005-07-05 00:00	0,7	188,0	319,0	19,1	1,8
2005-09-14 18:00	2,4		16,0	22,4	1,5
2005-09-14 21:00	1,8		280,0	19,1	1,4
2005-09-15 00:00	3,8		314,0	18,5	7,1
2005-09-15 03:00	2,2		339,0	19,8	6,2
2005-09-15 06:00	4,1		355,0	22,1	7,3
2005-09-15 09:00	3,1		34,0	25,6	6,7
2005-09-15 12:00	3,4		60,0	28,9	6,8
2005-09-15 15:00	4,1		349,0	28,7	7,3
2005-09-15 18:00	2,2		2,0	26,0	6,2
2005-09-15 21:00					
2005-09-16 00:00	2,1		311,0	18,7	3,5
2005-09-16 03:00	1,2		354,0	16,3	3,3
2005-09-16 06:00	0,7		335,0	15,8	3,1
2005-09-16 09:00	2,1		271,0	24,5	3,5
2005-09-16 12:00	2,3		190,0	26,0	3,6
2005-09-16 15:00	2,5		144,0	25,8	3,6
2005-09-16 18:00	2,1		88,0	23,8	3,5

2005-09-16 21:00	2,8	13,0	21,2	3,7

These episode sequences display great directional volatility. They apparently confound any attempt to summarise then in text or otherwise. Perhaps this is simply an indication that the events cannot be so characterised.

I think that the best hope is to try to obtain some more reliable, high resolution wind data which coincides with these episodes, and clean them for site effects, and then try to discern what is actually happening.

Some example predictions from WEng

Selecting the winds to model

So, given all this uncertainty, which winds should we feed into the WAsP software to generate some maps of wind speeds associated with high fire danger?

Let's examine the September 2005 episode, where in the midst of the highest danger, the wind direction apparently changed from NNW to NE and then back again six hours later.

We can use WAsP Engineering (WEng) to get prediction maps of speed and direction for nearby areas of the park (constrained severely by the limitations of the spatial data and site details explained in an earlier section).

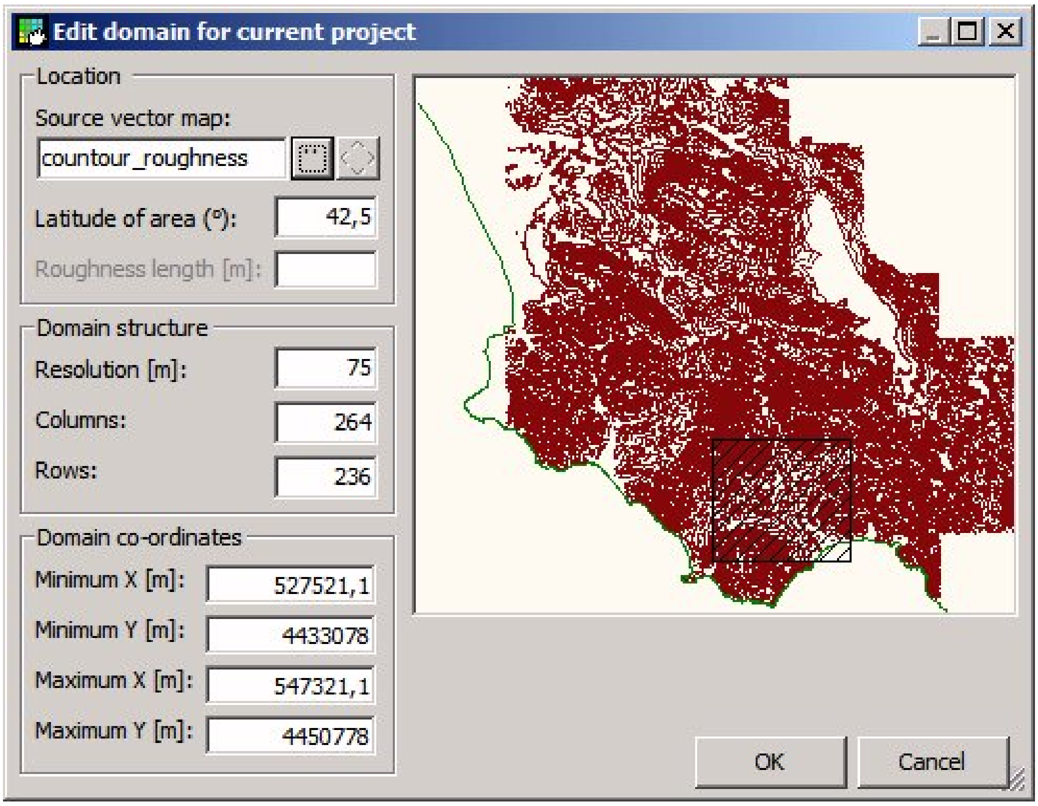
The following observed winds can be entered for the Policastro location…

- Direction 352 degrees, speed 4,1 m/s
- Direction 50 degrees, speed 3,25 m/s

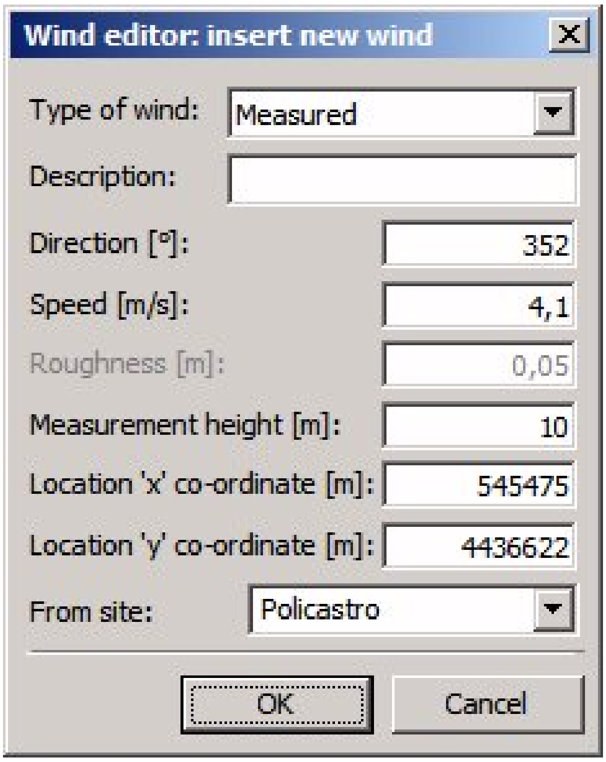
… and the effects of those changes on the predicted wind fields can be seen.

Going through the process in WEng

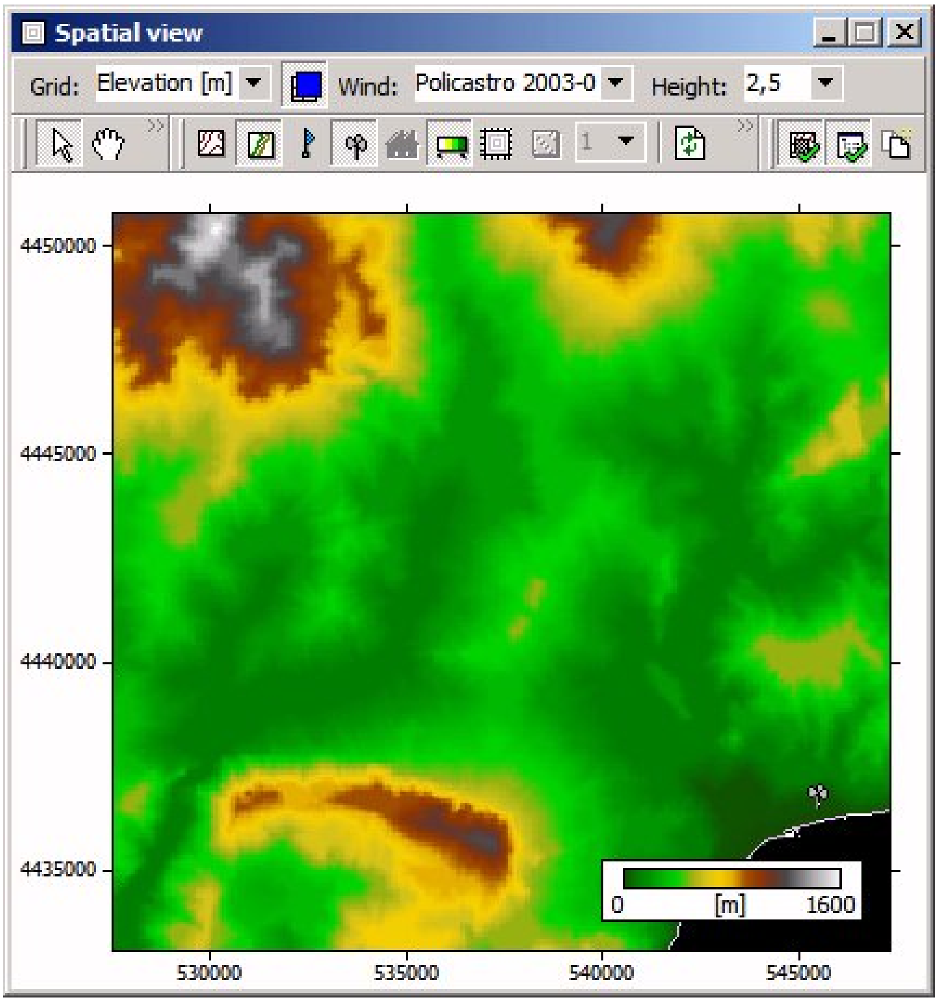
Opening our crude map in WEng, I selected an area inland to the north-west of the station. This is the 'project domain'.



Then I set up two measured winds for the Policastro site. Here's the dialog box for one of the winds.

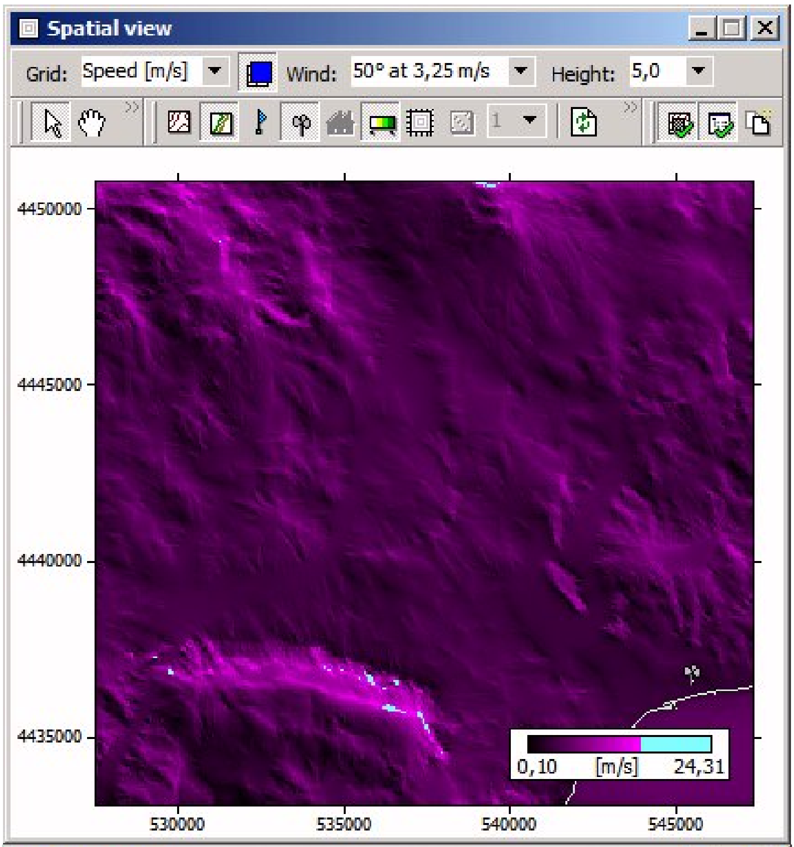


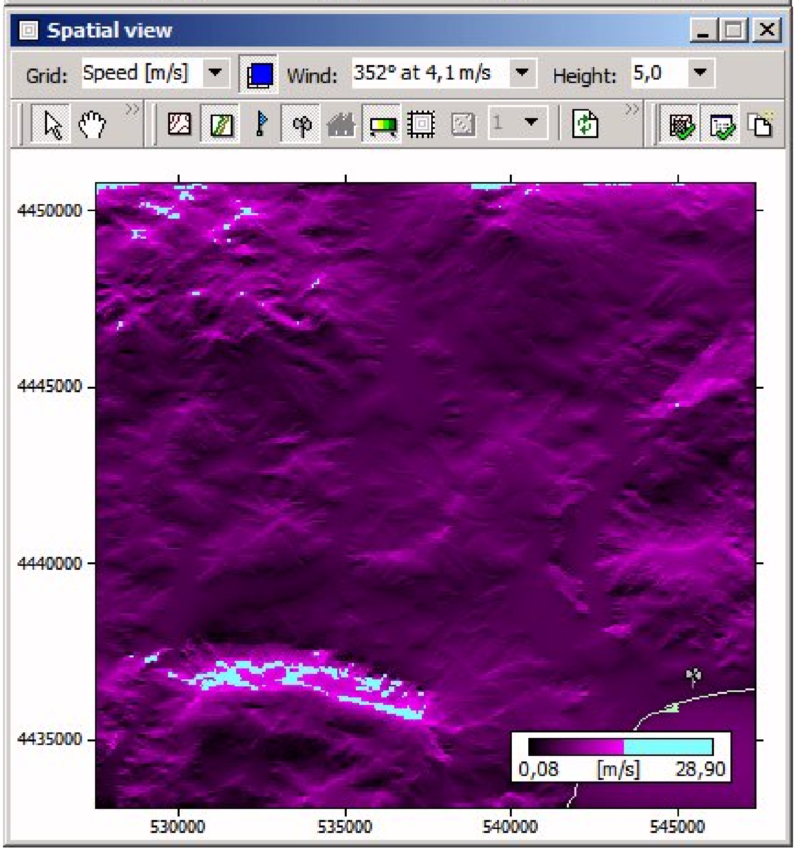
WEng creates grid maps for the domain. Here's the elevation grid which WEng derived, also showing the location of the measured winds (the anemometer icon in the bottom right).



I chose a default roughness length of 5cm for the land area, for want of any better data.

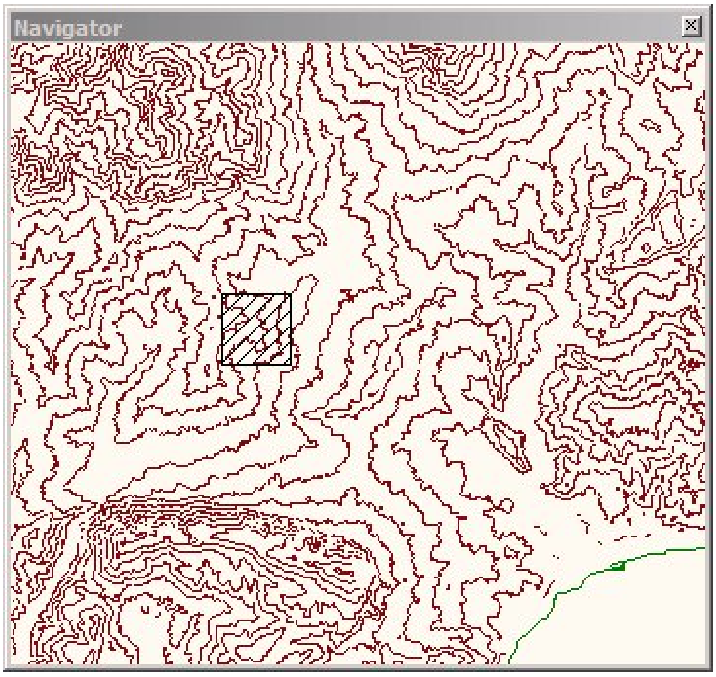
WEng calculates the wind field for any height requested. I chose 5m AGL. Here are the maps of predicted wind speed for our two winds for the whole area. Both have the same colour scale.



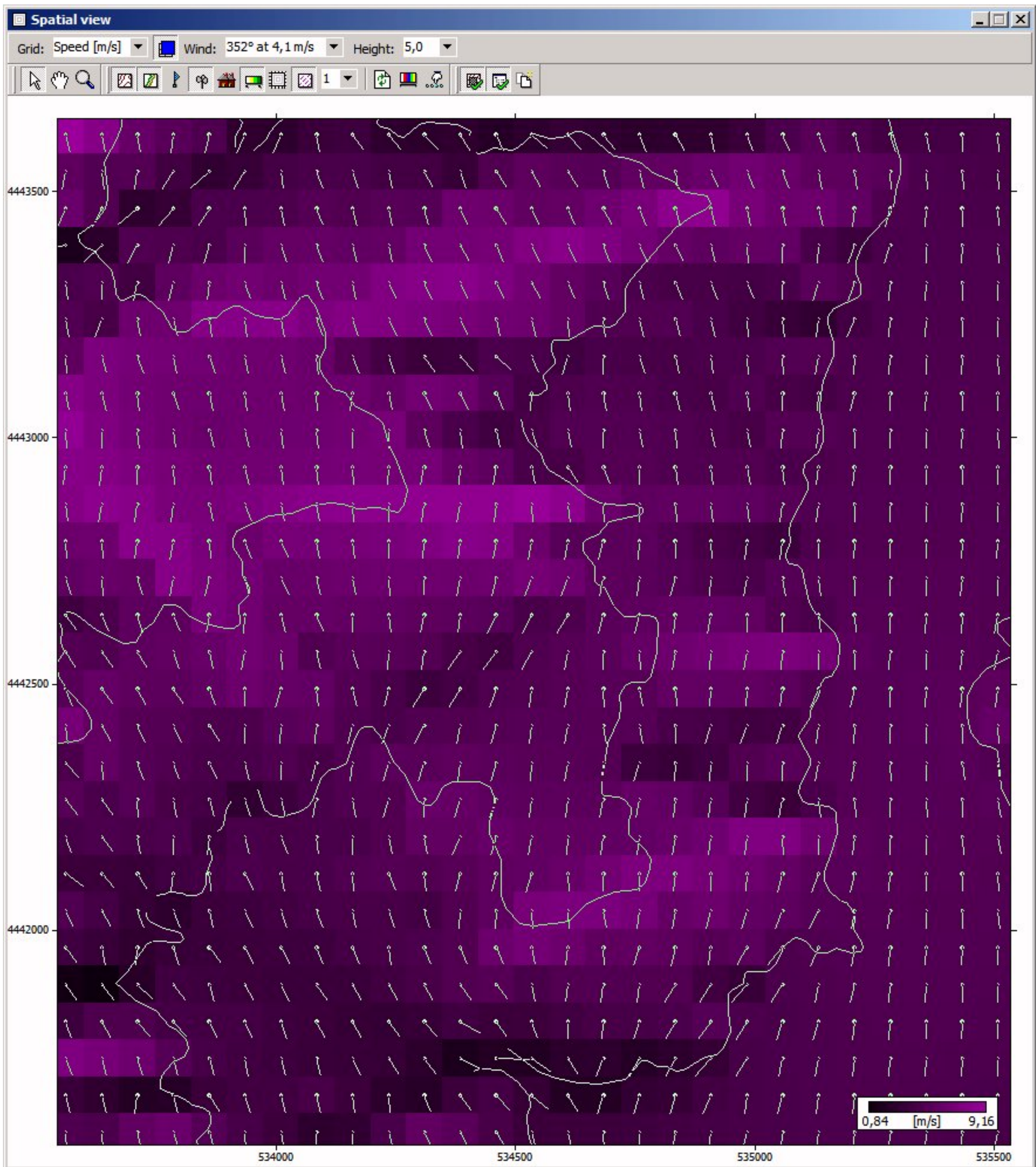


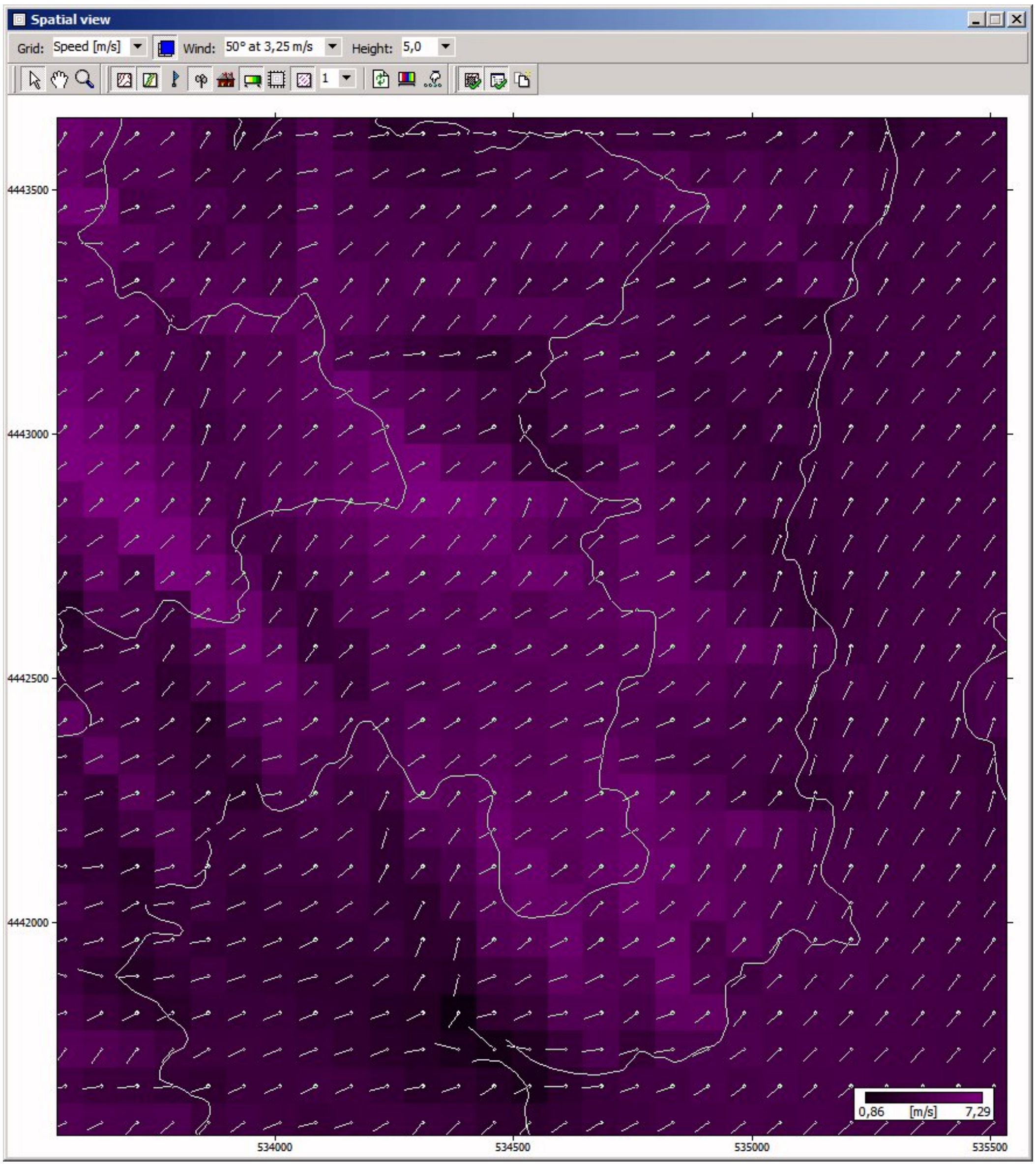
Whole-landscape maps like these are good for input to simulation models, but are not easy to interpret by eye. We can zoom in on a particular area and see more detail.

Let's look at the river valley north east of the escarpment, which lies within the park borders.



Here are some screen shots from WEng, showing the predicted speed (by colour) and direction (by line 'tails') over the highlighted area.


Spatial view
Grid: Speed [m/s]
Wind: 352° at 4,1 m/s
Height: 5,0
4443500
4443000
4442500
4442000
534000
534500
535000
535500
0,84 [m/s] 9,16



If we were able to have confidence in the results, then the two maps would presumably be very significant in understanding the changes in a fire's spread during the course of the day.

Future work - what next?

This preliminary work needs to be completed, and perhaps extended. Here is a summary list of the tasks which most obviously arise.

- Obtain a longer time series of three-hourly data and generate longer time series of FDI values. Identify more danger 'episodes', and compare these with actual fire history to check whether there is any correspondence.
- Compare the sequence of danger episodes for the three sites. Is there any correspondence? Do they seem to share the same fire danger climate most of the time?

- Obtain at least a short period of higher resolution data, and detailed information about the measurements and sites. Examine a fire danger episode in more details, and try to understand the recorded changes in direction: is there any discernable pattern?
- Look for diurnal patters in the wind speed and direction. Try using three-hourly temperature data for calculating the three-hourly danger index values. That might deal with any diurnal effects.
- Transform the vegetation types map into a map of roughness changes and add that information to the WEng data set.
- Find out more information about the sites' exact location and surroundings, so that the site effects can be 'cleaned'.
- Compare the three sites' cleaned wind climates: is there any correspondence? Is there some way we can justify arriving at interpolated values for other locations?
- Examine the probability distribution of fire danger. Is there some statistical distribution which could be fitted to the data, allowing us sensibly to analyse to some summary numbers for different sectors (as we do for mean and extreme wind speeds in WAsP and WEng)?
- Resolve open questions about the correct calculation of the Italian Fire Danger Index. Recalculate results as necessary.