Stability of Atmospheric Flow & Low-Level Jets Influencing Forest Fire Evolution Behavior

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Introduction

During the past years, there has been a considerable number of occasions that a forest fire burns with such strong intensity that seems far out of proportion to apparent burning conditions. This proved to be the case for the Sweden fire "blow-up" that took place during 4 August 2014.

On the afternoon of Thursday 31 July 2014 a wildfire broke out on the border between Sala and Surahammar municipalities in Sweden. This fire proved to be the Sweden's largest wildfire in 40 years with a duration of 14 days (31 July to 13 August 2014). The fire broke out after an unusual spell of hot, dry summer weather in northern Europe. The fire was declared a national emergency. It finally encompassed an area of ~15,000 hectares.

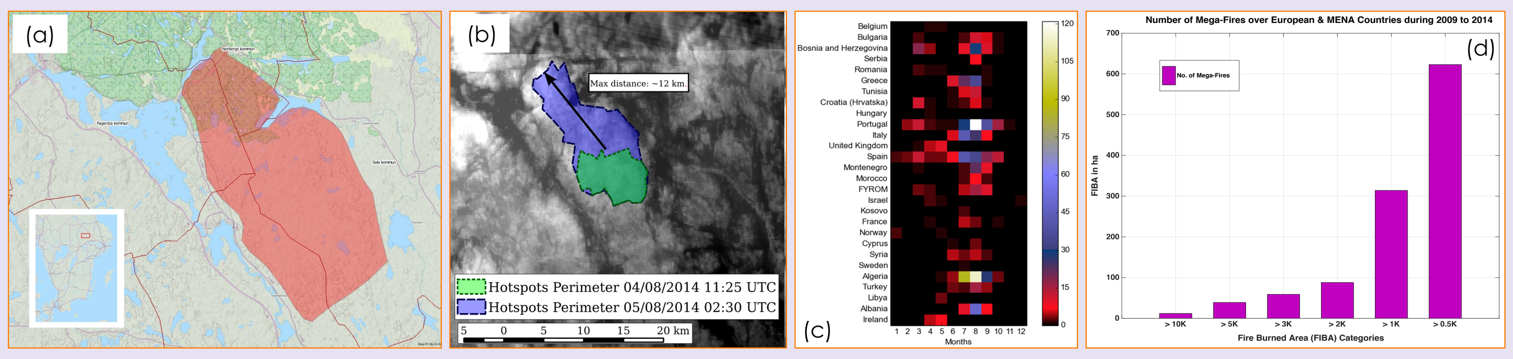

Figure 1. (a) Details of FIBA for Sweden Megafire. (b) Details of FIBA during fire's blow-up. (c) Inter-annual variability of large fires during 2009 to 2014. (d) Number of Megafires falling into different FIBA categories with Sweden fire belonging in Top12.

Data & Methodology

Details of estimated FIBA (FIre Burned Area) are given in Figure 1 (a) while details of the blow-up event are shown in (b). Inter-annual variability and frequency details of various FIBA categories for large fires (Megafires) from 2009 to 2014 taken from the European Fire Database (EFD) of the European Forest Fires Information System (EFFIS) [1] are given in (c) & (d) respectively.

Both Haines Index (HI) and Continuous HI (CHI) [2] give an indication about the potential for a fire "blow- up" due to low stability values of the atmosphere. A fire blow-up would lead to erratic / extreme fire behavior.

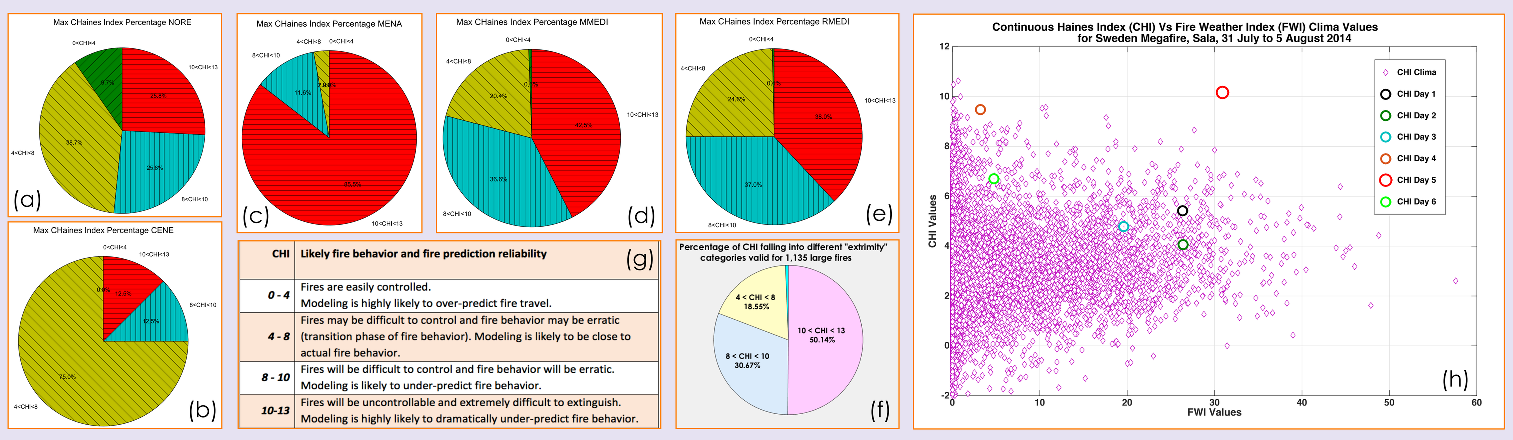

Figure 2. (a) Percentage of CHI values falling into different "extremity" categories for northern Europe (NORE). (b) As in (a) but for central Europe (CENE). (c) As in (a) but for MENA countries. (d) As in (a) but for Portugal, Spain, France, Italy & Greece (MMEDI). (e) As in (a) but for the rest of Mediterranean (RMEDI) countries. (f) As in (a) but for all European & MENA countries. (g) Fire behaviour and fire prediction reliability [2] based on CHI "extremity" categories. (h) CHI versus FWI values over the centroid of Megafire. Values are spanning 30 years (1980 to 2009). CHI & FWI Megafire values are also plotted.

From Figure 2 (f) it becomes clear that that more than 80% of the total number of large fires is falling in the two top extremity categories of CHI. Based on such significantly high percentage, it seems more than likely that low stability conditions had been accompanied most of the large fires during the last six years.

It is also obvious from (h) that during the "blow-up" day (Day 5) both CHI and Fire Weather Index (FWI) [1] were getting extreme ("saturated") values.

References

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Results

Close investigation of fire weather parameters revealed the existence of an upper-air trough linked to a dissolving warm front on the previous day (3 August) providing low stability values over fire centroid and the approach of a cold front from southwest further lowering the stability of the atmosphere.

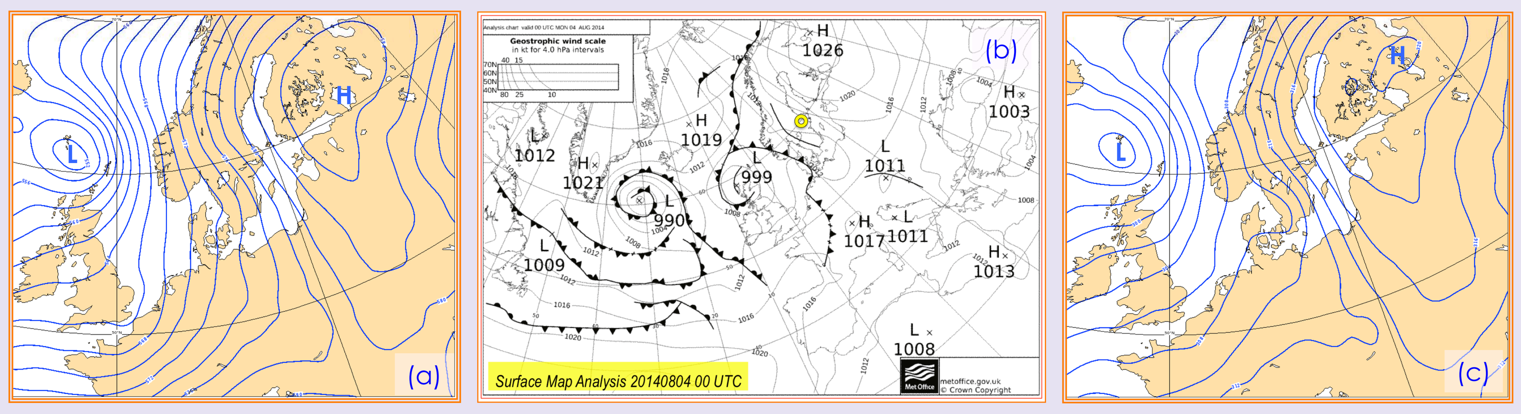

Figure 3. (a) ECMWF 500 hPa analysis of 4 August 12 UTC revealing an upper omega circulation. (b) UK Met Office weather map valid for 4 August (00 UTC). The position of fire centroid is indicated by a yellow circle. (c) As in (a) but for 700 hPa.

But above all, the air dryness and the prevailing of strong surface wind gusts due to a Secondary Low-Level Jet (SLLJ) at 950 hPa accompanied by a low level short-wave trough most pronounced at 700 / 800 hPa made ideal conditions for such an extreme event.

It is important to point out that the left entrance area of SLLJ would have allowed a circulation pattern as shown in Figure 4 (b) to feed dry air (by a direct downward current) the fire during the critical hours of 4 August.

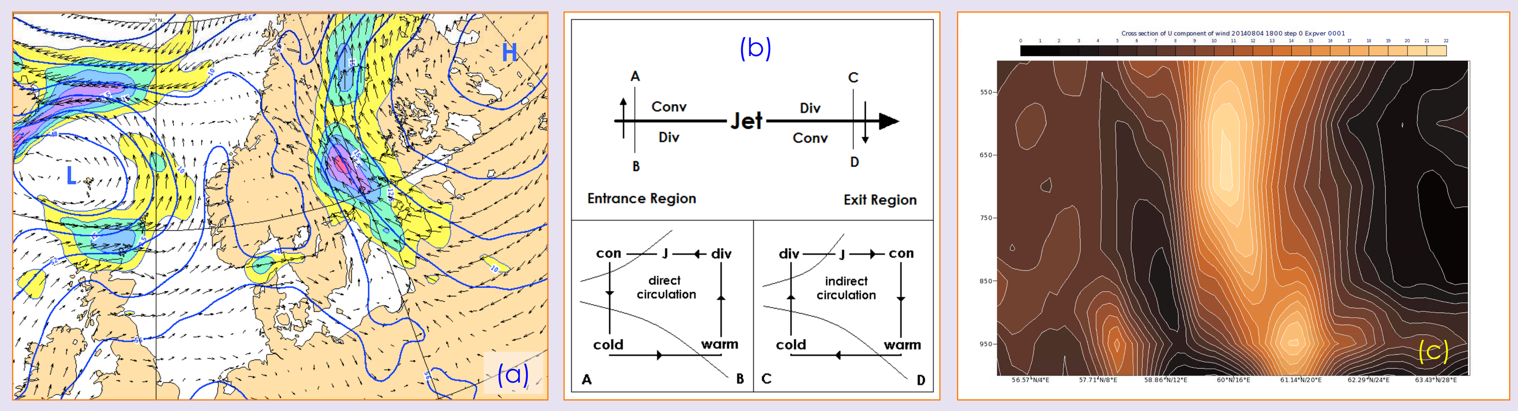

Figure 4. (a) ECMWF 950 hPa geopotential and wind analysis (T+00) of 4 August 18 UTC. (b) Transverse ageostrophic wind components and patterns of divergence associated with the entrance and exit regions of a jet streak adapted from [3]. (c) Vertical cross section depicting the Low-Level Jet (LLJ) at 700 and the Secondary LLJ (SLLJ) at 950 hPa.

The time that SLLJ was crossing and intensifying over and to the east of fire centroid found to be in agreement with the position and movement of the area of maximum instability as defined by the very high (and at times "saturated") values of Haines index (HI) & CHI. Such high HI / CHI values were also combined by an almost "saturated" daily Fire Weather Index.

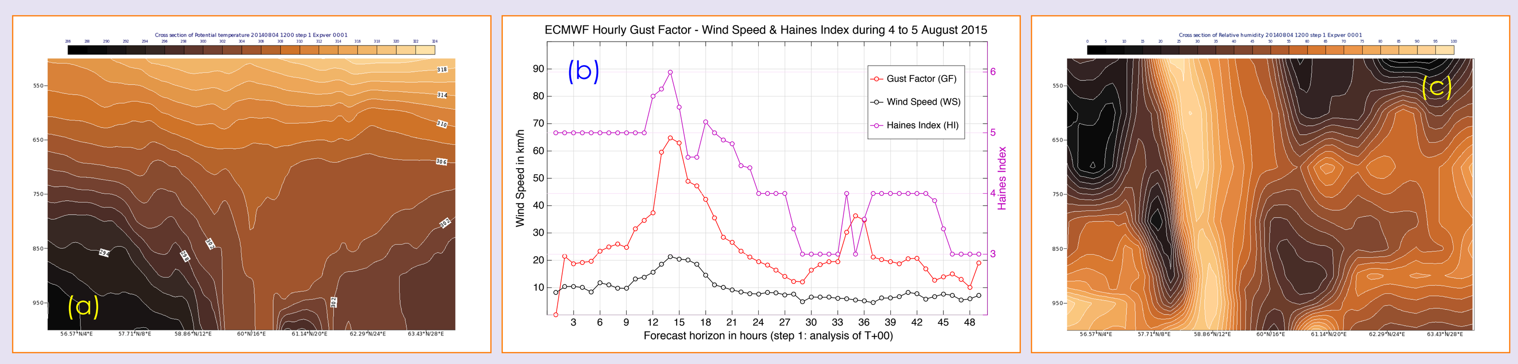

Figure 5. (a) ECMWF cross section of potential temperature surfaces valid for 12 UTC (4/8) with 304°K potential temperature surface bending downwards and "hitting" directly the position of fire centroid. (b) Cubic hourly simulation of GF, WS and HI during 4 to 5/8 2014. (c) Vertical cross section revealing low values of RH reaching at ground level (18 UTC).

Most of the initial simulations utilising ECMWF instantaneous wind speed values, as driving terms for EFFIS (European Forest Fires Information System) fire evolution models, namely FireSim [4] and FARSITE [5] were inaccurate due to errors in the intensity and gustiness of true prevailing winds.

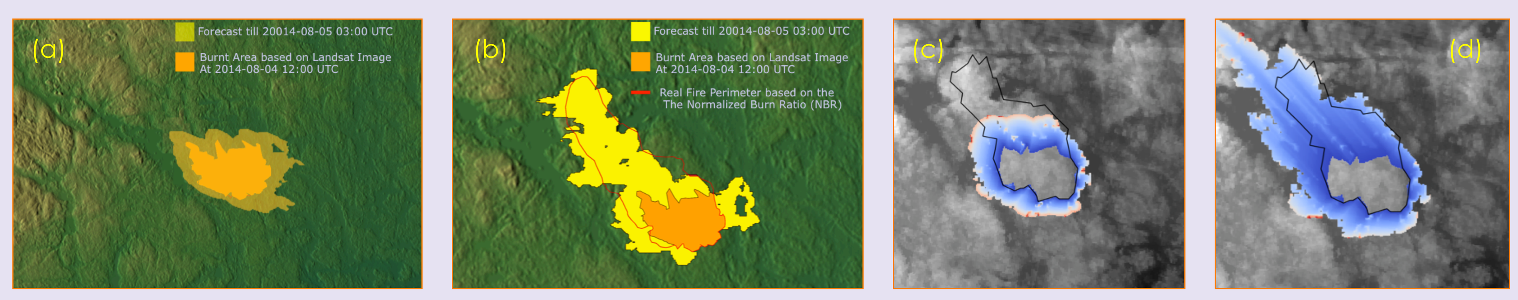

Figure 6. Fire spread details as being simulated by EFFIS FireSim utilising WS (a) and GF (b) input parameters. Fire spread details by FARSITE utilising WS (c) and GF (d) – Duration of simulations: from 12:00 UTC (4/8) till 03:00 (5/8).

Main Messages

By introducing model gust factor values (GFs) [6] instead of instantaneous speeds (WSs) significant improvement in accuracy was accomplished in all fire evolution simulations.

Overall, it seems quite important to consider the concept of atmospheric stability, dryness and the presence of LLJ / SLLJ as key elements in the forest fire management system particularly in circumstances conducive to interactions within the PBL (Planetary Boundary Layer).

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