On influence of wild-land fires on European air quality

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Wild-land fires: specifics of AQ impact

- Regular phenomenon, repeating nearly every year with varying intensity

**Anthrop.**

**ENVISAT:**

- Socio-environmental phenomenon: in populated regions up to 90% of fires are man-made

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- Releases pollutants and green-house gases into the atmosphere

- Destroys large areas of forests, savannas, steppes, etc.

- Frees-up the space in forests for new trees, thus facilitating the carbon fixation

- Cleans out the space from old and dead vegetation

**Birch:**

- Fires:
  - Cleans out the space from old and dead vegetation

- NB: areas with very efficient fire protection need further intervention to keep them clean from fuel for future ever-bigger fires

Fires:

- Impact on AQ: strongly episodic, varying from negligible to dominating

- Chemicals released: a wide range, strongly dependent on type of fire, weakly - on type of vegetation (but the fire type is affected by vegetation in its turn)

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**Apr-May 2006: Development of the episode**

**Forecast for: 12:00, 29APR2006**

- **Anthrop. PM 2.5**
- **PM 2.5 from fires**
- **Birch pollen**

- Concentr. Total PM 2.5 ug/m3
- Concentr. PM2.5, fires, ug/m3
- Concentr. birch pollen, grains/m3
Information sources on fires

• In-situ observations and fire monitoring
  ➢ pretty accurate when/where available
  ➢ costly and incomprehensive in many areas with low population density

• Remote-sensing products
  ➢ burnt area inventories on e.g. monthly basis (registering the sharp and well-seen changes in the vegetation albedo due to fire)
  ➢ hot-spot counts on e.g. daily basis (registering the temperature anomalies)
  ➢ fire radiative power/energy and similar physical quantities on e.g. daily basis (registering the radiative energy flux)

• Impact on air quality is highly dynamic, thus temporal resolution and timeliness play the key role
Fractionation of the fire energy

For moderate fires, the total energy release splits to radiative, convective and thermal-conduction forms as:

\[ \epsilon = \text{Radiation (40\%)} + \text{Convection (50\%)} + \text{Conduction (10\%)} \]

- The split is valid for a wide range of fire intensity
- The split is stable for various types of land use

Empirical formula for total rate of emission of FRP:

\[ Ef = 4.34 \times 10^{-19} \left( T_4^8 - T_{4b}^8 \right) \text{[MWatt per pixel]} \]

\( T_{4,4b} \) is fire and background brightness temperatures at 3.96 \( \mu \text{m} \) \((\text{Yoram Kaufman et al, 1998})\)
Total Fire Radiation Energy (FRE) vs. Fuel Consumption

$R^2 = 0.7468$
Regional AQ forecasting system of FMI

Satellite observations -> Fire Assimilation System

Phenological observations -> Phenological models

Aerobiological observations

Physiography, forest mapping

SILAM AQ model

HIRLAM NWP model

UN-ECE CLRTAP/EMEP emission database

Meteorological data: ECMWF

EVALUATION: NRT model-measurement comparison

Online AQ monitoring

Final AQ products
Current Fire Assimilation Systems

• Fire Alert System for Finland
  - about a decade-old, qualitative fire detection system for Finnish territory
  - automatically generates alert faxes for the municipal authorities
  - ATSR + AVHRR (night-time) + MODIS (morning)

• Fire Assimilation System v.0.9 and v.0.99
  - v.0.9: started in spring 2006, updated, recalibrated and automated to v.0.99 in November 2007
  - MODIS (Aqua + Terra) hot-spot counts represented as temperature anomalies: NASA Rapid-Response System
  - evaluates only PM 2.5 directly emitted from fires, empirical emission coefficient (recalibrated to v.0.99)
    - global, daily, 1km in irregular grid;
      - aggregated into 10km regular grid and cut down to European area

• Fire Assimilation System v.1.0
FAS v.0.9: experience

- April-May 2006: spring episode
  - first real test of the new system
  - very decent timing, acceptable absolute levels
  - case published in Atmospheric Environment
  - But:
    - second day is lost (clouds => no fire reports)
    - only PM 2.5 while e.g. in Sweden there was also an ozone peak,

Saarikoski et al, 2007
FAS v.0.9: experience (2)

- August 2006:
  - major fires in the south,
  - Finland is affected by a few small-scale but close-in-space events
- timing again almost perfect
- but:
  - absolute levels are 10-20 times underestimated (!!!)
  - fires are on and off many times: convective clouds obscure the reports
  - a fire field is again pretty homogeneous
Goals for FAS v.0.99 and v.1.0 development

• → v.0.99: Recalibrate and streamline the v.0.9 algorithm
• → v.1.0:
  ➢ Improve the evaluation of the emission fluxes by using FRP product
    – better accounting for fire intensity
    – improved spatial distribution of emission fluxes
    – evaluate the uncertainty by comparing the hot-spot- and FRP-based approaches (v.0.99 and v.1.0)
    – extend the list of emitted species
  ➢ Build the baseline system for the next steps
    – variation of emission factors with regard to land-use and vegetation type and state
    – other-than-MODIS satellites as the system input
    – input information for injection height evaluation
    – observation / modelling of fire development and diurnal variation
MODIS fire-related products

<table>
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<tr>
<th>Product</th>
<th>Source</th>
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<td>Level 2 and most Level 3 fire products:</td>
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<tr>
<td>MOD14, MYD14</td>
<td>EOS Data Gateway (see Section 3.1).</td>
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<tr>
<td>MOD14A1, MYD14A1</td>
<td></td>
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<td>MOD14A2, MYD14A2</td>
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<td>Level 2G fire products:</td>
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<tr>
<td>MOD14GD, MOD14GN</td>
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<tr>
<td>MVD14GD, MYD14GN</td>
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<td>CMG fire products:</td>
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<td>MOD14CMH, MYD14CMH</td>
<td>University of Maryland (see Section 3.2).</td>
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<td>MOD14C8H, MYD14C8H</td>
<td></td>
</tr>
<tr>
<td>Active fire locations in ASCII and ESRI shape file</td>
<td>MODIS Web Fire Mapper</td>
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<td>Fire and corrected-reflectance JPEG imagery and ASCII fire locations.</td>
<td>MODIS Land Rapid Response System</td>
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FAS v.1.0 information flow

Download manager (operational):
Global set Aqua & Terra 1 km granules for current date

Spatial operations (operational):
• Regriding & Aggregation for 10 km grid
• Quality Check
• Masking and Emission Calculation
• Temporal aggregation
• Complex spatial analysis

SILAM Interface (ongoing):
Automatic SILAM input file generation
Hot-spot counts vs FRP

Hot spots
per-pixel statistical database (time-integrated May-August 2006)

FRP

Mark size is proportional to temp. anomaly
Dot size is proportional to FRP
Area-integrated FRP: time series for 5 months
April-August 2006

x (D.D.) : 1 to 73 (summed)
y (D.D.) : 34.1 to 80.1 (summed)
DATA SET: frp083og
Pattern of emission coefficients

- PAGE land-use, 250m => 10km-grid classification of prevailing land-type as a surrogate for emission factors

Fire pixels: May 2006
What/where/when is burning??

- Area-integrated emission from 3 land types for 2006: time series for 5 months April-August
Fire season 2006: PM 2.5 in air (v.0.99 vs v.1.0)

- Conc, PM2_5_v.0.9 vert.column, mg/m2
- Conc, PM2_5_v.1.0 vert.column, mg/m2

- Setup: start date 1.4.2006, end date 31.8.2006
- Meteorology: HIRLAM 6.4.4
May 3 p

Conc, PM2.5 v.1.0 vert.column, mg/m²
05:00 03MAY2006
August, 7: fire plume along GF
August 9: plume shifted to Finland
Comparison with ground-based observations

Oulu, city-cente, PM 2.5 obs vs PM 2.5 from fires
Conclusions on current FAS status

• Results of v.1.0 are substantially different from v.0.99
  - spatial patterns differ: a principal difference btw hot-spot counts and FRP

• Ways of evaluation
  - Direct verification of emission terms is not possible
  - Indirect verification involves SILAM as a bridge from emission fluxes to observed concentrations and AOD

• Results of comparison with observations (so far, qualitative)
  - the major fires create sufficiently strong signal distinguishable from other aerosol sources
  - details of the distribution and quantitative evaluation makes sense only for total aerosol with all sources included: anthropogenic, biogenic, microphysical, natural, fires
Challenges for FAS

• Refine the emission coefficients
  - land-use as a surrogate: persistent
    - a series of model calibration exercises (and/or AOD assimilation)
  - dynamic via
    - complementary products (biomass water content, NDVI, soil water, …)
    - data assimilation of AOD in the vicinity of the fires

• Dynamic injection height
  - small fires: updated BUOYANT model is on standby
  - large fires: deep convection parameterization

• Holes in the data (clouds et al)
  - mix MODIS with other satellites
  - fire model (parameterization) fed with actual and prognostic variables

• Snapshots to time series: heuristic fire modelling

• Fire forecasts
  - fire model (parameterization) fed with actual and prognostic variables
Landsat-based 30m land use coverage
Hot spots statistic by land types

Fire area km2 (1996-2005)
Fuel type identification example
Cross validation of Landsat and Iconos land use
Challenges: details (1)

- Refine the emission coefficients
  - land-use as a surrogate: persistent
    - a series of model calibration exercises (and/or AOD assimilation)
  - dynamic via
    - complementary products (biomass water content, NDVI, soil water, ...)
    - data assimilation of AOD in the vicinity of the fires
Bog fire plume from Modis
AOD algorithm limitations
IS4FIRES: integrated system development

- WP 1. The detection of wild-land fires and smoke plumes by satellite observation techniques (link to GEMS)
- WP 2. Development of atmospheric dispersion modelling, data assimilation and source apportionment methods
- WP 3. Detection and quantification of particulate matter formed in fires at surface measurement stations, and the related modelling (link to EUCAARI)
- WP 4. Organisation of a forest fire dispersion measurement campaign in the vicinity of the SMEAR2 station, and the related modelling (link to EUCAARI)
- WP 5. Evaluation, analysis and modelling of the aerosol data measured during the TROICA campaign
Thank you for your attention!

- P.S. SILAM operational fire plume forecasts are available form [http://silam.fmi.fi](http://silam.fmi.fi)