Scientific Recommendations Land-Atmosphere:
Wildfires / Biomass Burning

J.W. Kaiser

contributions from:
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M. Sofiev, C. Textor
Outline

- Introduction
- GEMS / GEOLAND Requirements
- Available Data
- Recommendation
- Summary
INTRODUCTION
What is Biomass Burning (BB)?

- **biomass:**
  - green vegetation, wood, litter, soil organic matter, peat
- **ignition:**
  - lightning or human activity
- **visible from space by thermal radiation or burnt area**
  - gas flares etc. excluded from observations
- **function:**
  - natural cycle of ecosystem
  - deforestation
  - agriculture
  - accident
  - ...
- **a.k.a. “vegetation fires”, “wildfires”**
Annual Fire Emissions, averaged over 1997–2004

[Van der Werf et al., ACPD 2006]
Significance for Land Monitoring

- Wildfires are an important sink mechanism for the terrestrial carbon pools in the global carbon cycle.
  - wildfire emissions, typical global values: 1.5 – 4 Gt C / year
  - fossil fuel emissions of Europe + North America: 3 Gt C / year

- Wildfire behaviour characterises land cover types with repeated fire events.
  - typical fire repeat period
  - typical fire intensity
  - typical fire seasonality
  - …

- Wildfires can change the land cover type reversibly
  - tropical deforestation
  - …
Atmosphere: Biomass Burning (BB) Emissions ...

**AIR QUALITY:**
- ... can dominate local and regional air quality with poisonous smoke
- ... can elevate background of atmospheric pollutant after long range transport [Stohl et al. 2001, Forster et al. 2001, Andreae et al. 2001]

**POLLUTION CONTROL:**
- ... significantly contributes to global budgets of several gases
  - Kyoto, CLRTAP, ...

**WEATHER:** (absorbing aerosols)
- ... influences the radiative energy budget [Konzelmann et al., JGR 1996]
- ... provides cloud condensation nuclei [Andreae et al., Science 2004]
- Heat release accelerates deep convection. [Damoah et al., ACP 2006]

**REMOTE SENSING:**
- ... affects essential a priori information for remote sensing (AOD, profiles)

**CHALLENGE:**
- ... are highly variable on all time scales from hours to decades
GMES REQUIREMENTS
# GEMS/GEOLAND BB Product Requirements

<table>
<thead>
<tr>
<th></th>
<th>GEMS</th>
<th>GEOLAND</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PRODUCTS</strong></td>
<td>amounts of trace gases (CO2, CH4, CO, O3, NO2, SO2,...) and aerosols emitted</td>
<td>amount of biomass burnt</td>
</tr>
<tr>
<td></td>
<td></td>
<td>type of vegetation burnt</td>
</tr>
<tr>
<td></td>
<td></td>
<td>date and location of fire</td>
</tr>
<tr>
<td></td>
<td></td>
<td>date and location of fire</td>
</tr>
<tr>
<td></td>
<td></td>
<td>injection height profiles</td>
</tr>
<tr>
<td><strong>COVERAGE</strong></td>
<td>spatial:</td>
<td>global, consistent</td>
</tr>
<tr>
<td></td>
<td>temporal: &gt; 8 years</td>
<td>&gt; 10 years, consistently</td>
</tr>
<tr>
<td><strong>RESOLUTION</strong></td>
<td>spatial: ≈ 25 km</td>
<td>(1 km for GEOLAND-2)</td>
</tr>
<tr>
<td></td>
<td>temporal: 1-6 hours</td>
<td>1 day</td>
</tr>
<tr>
<td><strong>AVAILABILITY</strong></td>
<td>near-real time</td>
<td>retrospectively</td>
</tr>
</tbody>
</table>

[Kaiser et al. 2006]
AVAILABLE DATA
Two types of fire products accessible from Earth obs. systems

- **ACTIVE FIRE product**
  - Active fire
  - Hot spot
  - Fire pixel
  - Fire count

- **BURNT AREA product**
  - Burnt area
  - Burnt pixel
  - Burnt scar

**OBSERVATIONS**

- **Area burnt**
  - spectrally flat
  - BRDF flat
  - dark
  - only after fire

- **Fire front**
  - thermal emission, MIR
  - only during fire
# Observation System: Current Fire Products

## Active Fire Products (no quantitative information)

<table>
<thead>
<tr>
<th>NAME</th>
<th>REFERENCE</th>
<th>SENSOR(S)</th>
<th>COVERAGE</th>
<th>RESOLUTION</th>
<th>AVAILABILITY</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODIS active fire</td>
<td><a href="http://modis-fire.umd.edu/products.asp">http://modis-fire.umd.edu/products.asp</a></td>
<td>Aqua/Terra-MODIS</td>
<td>global</td>
<td>2001 – present</td>
<td>1 km</td>
<td>1 day</td>
</tr>
<tr>
<td>World Fire Atlas</td>
<td><a href="http://dup.esrin.esa.int/onia/wfa">http://dup.esrin.esa.int/onia/wfa</a></td>
<td>ERS2-ATSR2, Envisat-AATSR</td>
<td>global</td>
<td>1995 - present</td>
<td>1 km</td>
<td>1 day</td>
</tr>
<tr>
<td>Active Fire Monitoring (FIR)</td>
<td><a href="http://www.eumetsat.int/idcplg?idcService=SS_GET_PAGE&amp;nodeid=522">http://www.eumetsat.int/idcplg?idcService=SS_GET_PAGE&amp;nodeid=522</a></td>
<td>Meteosat-SEVIRI</td>
<td>Africa &amp; Europe</td>
<td>3 km</td>
<td>15 min</td>
<td>NRT</td>
</tr>
<tr>
<td>IGBP-GFP</td>
<td><a href="http://www-temp.jrc.it/">http://www-temp.jrc.it/</a></td>
<td>NOAA-AVHRR</td>
<td>global</td>
<td>1992-1993</td>
<td>1 km</td>
<td>1 day</td>
</tr>
<tr>
<td>TRMM</td>
<td><a href="http://earthobservatory.nasa.gov/Observatory/Datasets/fires.trmm.html">http://earthobservatory.nasa.gov/Observatory/Datasets/fires.trmm.html</a></td>
<td>TRMM-VIRS</td>
<td>40°N - 40°S</td>
<td>1988-2002</td>
<td>2 km / 0.5° (sensor/product)</td>
<td>1 month</td>
</tr>
</tbody>
</table>

## Active Fire Products with quantitative information

<table>
<thead>
<tr>
<th>NAME</th>
<th>REFERENCE</th>
<th>SENSOR(S)</th>
<th>COVERAGE</th>
<th>RESOLUTION</th>
<th>AVAILABILITY</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>WF_ABBA, Dozier method</td>
<td><a href="http://climss.ssec.wisc.edu/goes/burn/detection.html">http://climss.ssec.wisc.edu/goes/burn/detection.html</a></td>
<td>GOES-E/W</td>
<td>N/S America</td>
<td>1995-present</td>
<td>4 km</td>
<td>30 min</td>
</tr>
<tr>
<td>MODIS FRP</td>
<td><a href="http://modis-fire.umd.edu/products.asp">http://modis-fire.umd.edu/products.asp</a></td>
<td>MODIS</td>
<td>global</td>
<td>2001-present</td>
<td>1 km</td>
<td>1 day</td>
</tr>
<tr>
<td>global FRP from GEOs</td>
<td>M. Wooster, private comm.</td>
<td>several GEO satellites</td>
<td>global</td>
<td>4 km</td>
<td>30 min</td>
<td>NRT</td>
</tr>
</tbody>
</table>

## Burnt Area Products

<table>
<thead>
<tr>
<th>NAME</th>
<th>REFERENCE</th>
<th>SENSOR(S)</th>
<th>COVERAGE</th>
<th>RESOLUTION</th>
<th>AVAILABILITY</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLOBSCAR</td>
<td><a href="http://dup.esrin.esa.int/onia/projects/summaryg24.asp">http://dup.esrin.esa.int/onia/projects/summaryg24.asp</a></td>
<td>ERS2-ATSR2</td>
<td>global</td>
<td>2000</td>
<td>1 km</td>
<td>1 month</td>
</tr>
<tr>
<td>MODIS Fire Affected Area</td>
<td><a href="http://modis-fire.umd.edu/products.asp">http://modis-fire.umd.edu/products.asp</a>#8</td>
<td>Aqua/Terra-MODIS</td>
<td>global</td>
<td>2001-present</td>
<td>500 m</td>
<td>1 day</td>
</tr>
<tr>
<td>Global Daily Burnt Area (GDBAve1)</td>
<td><a href="http://www-temp.jrc.it/fire/gba2000">http://www-temp.jrc.it/fire/gba2000</a></td>
<td>SPOT-VGT</td>
<td>global</td>
<td>2000-2005</td>
<td>1 km</td>
<td>1 day</td>
</tr>
<tr>
<td>Burnt Area for GEOLAND (BAG)</td>
<td>[<a href="http://www-temp.jrc.it/fire/Restricted">http://www-temp.jrc.it/fire/Restricted</a> access (GEOLAND)](<a href="http://www-temp.jrc.it/fire/Restricted">http://www-temp.jrc.it/fire/Restricted</a> access (GEOLAND))</td>
<td>SPOT-VGT</td>
<td>Africa &amp; Eurasia</td>
<td>1988-2003</td>
<td>1 km</td>
<td>10 days</td>
</tr>
<tr>
<td>VGT4Africa</td>
<td><a href="http://www-temp.jrc.it/fire">http://www-temp.jrc.it/fire</a></td>
<td>SPOT-VGT</td>
<td>global</td>
<td>2005-present</td>
<td>1 km</td>
<td>1 day</td>
</tr>
<tr>
<td>GLOBCARBON</td>
<td><a href="http://dup.esrin.esa.int/projects/summaryp43.asp">http://dup.esrin.esa.int/projects/summaryp43.asp</a></td>
<td>ERS2-ATSR2, Envisat-AATSR, Envisat-MERIS, SPOT-VGT</td>
<td>global</td>
<td>1988-2007</td>
<td>8 km</td>
<td>1 month</td>
</tr>
</tbody>
</table>
OBSERVATIONS: Calculating Emission Amounts

- **traditional:**
  - Fire Radiative Power (FRP):
    - $M(X) = FRP \times \text{time} \times \text{scaling factor} \times \text{emission factor}(X)$

  

- **Globe:** ~ 400 millions hectares burnt in 2000
- **Med. Basin:** ~ 500000 hectares
- **Dry tropical grass savanna:** ~ 2 tons/hectare
- **Moist tropical savanna:** ~ 10 tons/hectare
- **Boreal forest:** ~ 20 tons/hectare
- **Moist tropical forest:** ~ 40 tons/hectare

  - ~ 25% forest → ~ 80% savanna
  - Woodland & forests
    - ~ 1600 g CO$_2$ / kg biomass
    - Grasslands
    - ~ 1700 g CO$_2$ / kg biomass

- Fuel: T. ha$^{-1}$

- Area burnt per vegetation type: ha

- "pixels" burnt per vegetation type

- OBSERVATIONS: Calculating Emission Amounts
Current NRT Fire Emission Monitoring Systems

- **NRL/NAAPS aerosol model in the FLAMBE project**
  - Additionally assimilates the MODIS active fire product
  - Delivers global aerosol emissions

- **RAMS model at INPE/CPTEC**
  - Assimilation of WF_ABBA product from GEOS satellites
  - Delivers CO and aerosol emissions over the Americas

Adapted from E. Prins
Global Fire Activities in GEMS @ ECMWF

- CO2 and aerosol fire emission from inventory GFEDv2
  [van der Werf et al., ACP 2006]
  - hot spot fire observations from satellite-borne MODIS
  - available fuel load from CASA vegetation model
  - no near-real time availability
  - time resolution: 8 days
  - Can be used as dummy for future fire monitoring system in reanalyses.

- “global” GEO FRP
  - participation in 2 new projects as user
Fire CO2 Emission on 20 Aug 2003 [g / m2 / day] (GFEDv2_8day, re-gridded to T159)
CO2 Model Field with Fires @ 500hPa [ppm]
Excess CO2 due to Fires [ppm]

Wednesday 20 August 2003 00UTC ECMWF Forecast t+12 VT: Wednesday 20 August 2003 12UTC Model Level 40 **Carbon Dioxide
Excess CO2 due to Fires II [ppm]

Cross section of co2 20030820 00 step 12 Expver esvu
No fire emissions

With fire emissions

(satellite data assimilation by R. Engelen, ECMWF)
RECOMMENDATION:
Global Fire Assimilation System
(HALO-GFAS)
Benefits of Near-real-Time fire information for GEMS & GEOLAND

- GEMS would benefit from near-real time fire information, but currently uses climatological fire information.
- Biosphere carbon monitoring in GEOLAND-2 would benefit from an accurate burnt biomass product, but the existing products have limited accuracy.
- A future service, HALO-GFAS, could use complementary satellite fire observations, plus a fire model, to provide:
  - Emissions
  - Profiles of emission injection heights
  - Pyro-change in biomass
- GEMS would benefit through more realistic and timely fire emission information.
- GEOLAND would benefit through estimates of change in carbon stocks.
- GFAS would benefit from fuel estimates provided by GEOLAND-2 as experience develops.
HALO-GFAS serves GEMS and GEOLAND.

- GEMS
  - fire emissions
  - injection heights
- GEOLAND
  - available fuel load
  - land cover type
  - pyro-changes in carbon stocks
- HALO-GFAS
  - fire observations
A GFAS is needed to provide the required fire input for the GMES land and atmosphere monitoring systems.

- Assimilation of the best available satellite products into a numerical model of the global fire activity including information on atmospheric conditions and land cover.
Additional HALO-GFAS Benefits

- single, consistent, operational fire processing for all GMES systems
  - global and regional
- GEOLAND will benefit from improved land cover characterisation and land cover change detection.
- Numerical Weather Prediction will benefit from fire heat release product for driving the convection.
- A multi-parameter inversion of the observed fire plumes will yield
  - improved fire emission fluxes (GEMS)
  - information on the fire properties
  - improvement of the fire model to be used by
    - HALO-GFAS
    - climate models

- Collaboration of space agencies, satellite retrieval experts, biosphere & atmosphere modellers, and other users
- “Expression of Interest” formulated (March 2006)
  - supported by 30+ scientist from 30+ institutions in Europe

- Funding needed!
SUMMARY

- GEOLAND-2, GEMS/GAS, will need global Biomass Burning modelling in near-real time and consistent multi-year time series.

- No single suitable EO product or monitoring service is available.

- We recommend to develop a Global Fire Assimilation System (HALO-GFAS) to serve the GMES requirements. It should combine:
  - fire EO products
  - meteorological conditions
  - land cover: ecosystem, biomass incl. all carbon stocks
  - numerical model of fire activity

- The recommended HALO-GFAS is widely supported in the European science community.

- HALO-GFAS needs funding and a host.
MORE INFORMATION

- www.ecmwf.int/research/EU_projects/HALO
- www.ecmwf.int/research/EU_projects/GEMS
- www.gmes-geoland.info
- j.kaiser@ecmwf.int

ACKNOWLEDGMENTS

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SCIENCE DISCUSSION
Issues in implementing/developing MERSEA, GEOLAND, GEMS in the period 2008-2013

- **OCEAN**
  - Current Ocean-Atmosphere set-up looks OK for 2008-2013
  - Ocean-Land issues look difficult
    - little can be done before 2013

- **LAND-ATMOSPHERE**
  - The main issue is how to quantify better the land-atmosphere interactions
  - biomass exchange of H2O, CO2, CH4 (GEOLAND-2)
  - Burnt biomass & emissions (GFAS)

- **GEOLAND-2**
  - Will assimilate satellite data on LAI, fAPAR,..,
    - either online in the IFS, or offline from the IFS
  - Will improve C-TESSEL through extensive validation
  - Will generate improved estimates of soil organic matter and forest biomass through modelling
  - Could generate surface flux estimates offline from IFS, from several SVATS including ORCHIDEE
  - GFAS will use biomass estimates and satellite data to provide
    - improved estimates of burnt biomass

- **GEMS/GAS** can use GEOLAND-2 products in several ways
  - Use C-TESSEL inline in IFS, and assimilate LAI data
  - Use offline GEOLAND-2 fluxes as additional information sources in an ensemble of synthesis inversions
  - The best utilisation can only be determined by experimentation

- GFAS needs funding and a host.