A SIMPLIFIED MODEL FOR THE STUDY OF SMOKE PLUME DISPERSION FROM GRASSFIRES AND A METHODOLOGY FOR FORECASTS VALIDATION WITH SATELLITE IMAGERY

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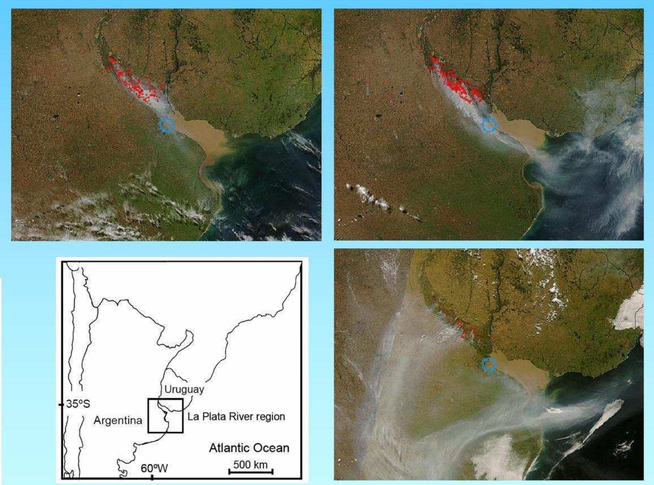
INTRODUCTION

GRASSFIRES IN THE PARANA RIVER DELTA
- Due to agricultural management practice for land clearing
- In April and May 2008
- Up to 570 fire locations and 70,000 hectares burnt out.

SMOKE EVENTS IN THE LA PLATA RIVER REGION
- Smoke propagated further away of that region in some cases
- Uncontrolled fire during April 16-20, affected Buenos Aires city in an extreme event without historical precedent

METEOROLOGICAL CONDITIONS
Droughts and persistence of anomalous northwesterly winds contributed to that situation, which under normal conditions for that time of the year would have not occurred.

SEVERE LOCAL AND REGIONAL IMPACT
- Increased health problems (respiratory problems, eye irritation, etc.).
- Hazardous driving conditions and accidents that forced the intermittent closure of highways, and inoperability of ports and airports.



Location of the La Plata River region in South America. MODIS real-color images (AERONET-CEILAP subset) from: a) AQUA, April 16 at 18.00 UTC; b) AQUA, April 18 at 17.50 UTC; c) TERRA, April 2016 at 15.00 UTC. Red dots correspond to MODIS automated fire detections. The blue circle indicates the location of Buenos Aires city .

THE HIRHYLTAD MODEL
HIgh-Resolution HYbrid Lagrangian Trajectory and Atmospheric Dispersion model

It is hybrid because:

- It uses a Lagrangian coordinate system (mobile) to calculate the trajectories of individual elements of the smoke plume, and an Eulerian framework (fixed) to calculate concentrations in a high resolution grid.
- It was created from a smoke line model, whose input is a forecasted wind field at discrete time intervals, and from the Gaussian model, which assumes homogeneous and stationary conditions, as well as continuity.

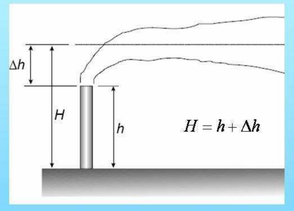
Adaptation of the Gaussian model (summary)

$$C(x,y,z)=\frac{Q}{2\pi u\sigma_y\sigma_z}\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left[\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)\right]$$

$$C_{i,j}(t)=\frac{Q}{2\pi\bar{u}(t)\sigma_{y\#}(t)\sigma_z(t)}\exp\left(\frac{-y_\#^2}{2\sigma_{y\#}^2(t)}\right)\exp\left(\frac{-(z-H(t))^2}{2\sigma_z^2(t)}\right)$$

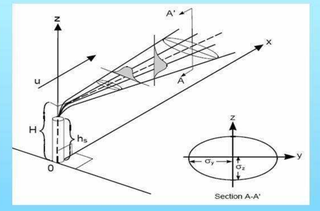
- Dependence on time
- Natural coordinates fixed to the plume axis: $x_\#$, $y_\#$
- Concentration on discrete (i,j) grid points, and for t=kΔt time intervals

Parameter sensitivity tests were performed (model calibration)



Δh = BUOYANT PLUME RISE
It is calculated using Briggs parameterization

H = effective emission height
h = physical emission height



THE GAUSSIAN MODEL

MAIN USES OF HIRHYLTAD
Small-scale high-resolution dispersion simulations

Phenomena
- smoke plumes originated by grassfires or forest fires
- stack emissions from factories

Applications
- Research / case studies (diagnostic mode)
- Operational forecasts

MAIN ADVANTAGES OF HIRHYLTAD
in comparison with other dispersion models widely used such as HYSPLIT

- It requires minimum data, i.e. wind, temperature and cloudiness
- It is easily coupled to a meteorological model
- It reduces computational costs

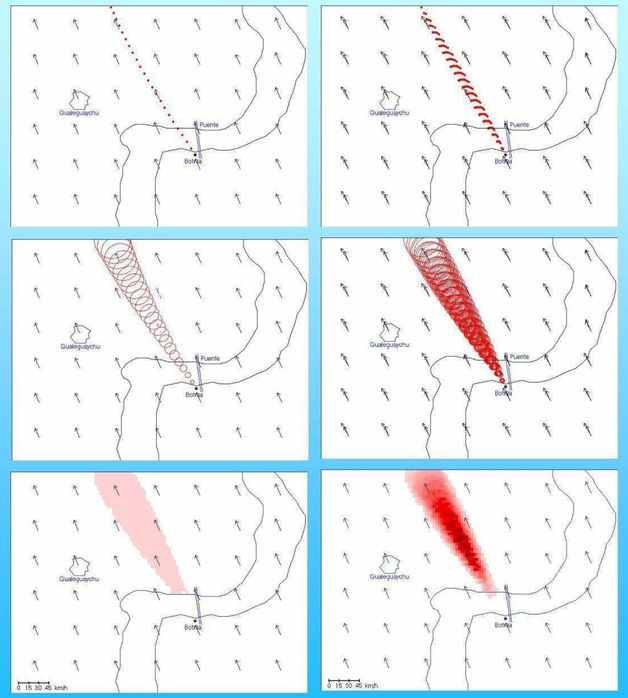
HIRHYLTAD STEPS:

1 – SMOKE LINE
with lagrangian trajectories

2 – SMOKE PUFFS IN THE HORIZONTAL
with Pasquill-Gifford dispersion coefficients and Pasquill stability classes

3 – SMOKE CONCENTRATIONS IN A HIGH RESOLUTION GRID
for a z-level / vertically integrated

INSTANTANEOUS EFFECT ACCUMULATED EFFECT



Figures obtained after a 2-hour simulation, showing 24 smoke line elements/puffs (model time step = 5 min) Panels below show surface concentrations; physical emission height = 120 m.

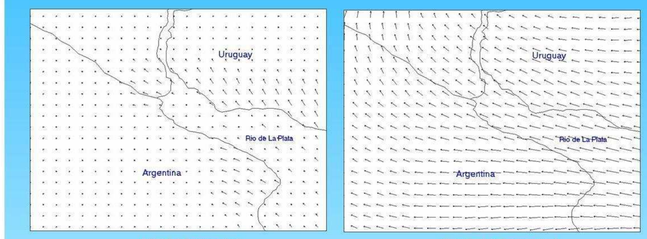
METEOROLOGICAL MODELS AND EXPERIMENTS

Eta/SMN REGIONAL MODEL
- Developed in the 70s in the former Yugoslavia by Mesinger and Janjic, and subsequently improved and upgraded at NCEP. Implemented at SMN in 2002.
- Horizontal domain: 30º-91º W and 14º-65º S; grid spacing of 1/3 º (30 km), and rotated spherical coordinate system
- Boundary and initial conditions are provided by the GFS model
- It runs in a hydrostatic mode, for 38 hydrostatic pressure levels in the vertical.
- It is operationally run twice a day (00 and 12 UTC) performing 120-hour forecasts at 3-hour intervals

MESOSCALE BOUNDARY LAYER MODEL (MBLM)
- Primitive equation, dry and hydrostatic
- High definition of the water-land temperature gradient
- Horizontal resolution: 0.05º (5km).
- Vertical domain: 12 levels distributed according to a log-linear spacing. 0.001, 10, 40, 80, 140, 220, 350, 550, 800, 1100, 1500, 2000.
- Upper boundary condition: geostrophic wind at the material top
- Lower boundary condition: definition of a surface heating function at z_0
- Data assimilation from observations (MBLM/obs) or large-scale model outputs

6 EXPERIMENTS PERFORMED, COMBINING:

- Eta/SMN — MBLM / obs — MBLM / EtaSMN
- Diagnostic mode — Prognostic mode



MBLM model ***Eta/SMN model***

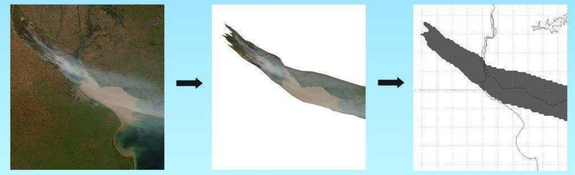
Examples of low level wind patterns obtained in the La Plata River region, for different meteorological situations. Eta/SMN outputs were post-processed in order to be coupled to the HIRHYLTAD dispersion model (spatial and temporal interpolations performed to increase resolution as in the MBLM model)

METHODOLOGY

SELECTION OF SMOKE EVENTS (w. associated fires) AND DIGITIZATION
Subjective process: smoke outlines are produced manually onto the MODIS 500m-res. imagery MODIS automated fire detection product was NOT USED (false detections + no detections)

SMOKE PLUME SIMULATIONS

COMPATIBILITY OF DATA FORMATS BETWEEN OBS. AND FCST. PLUMES
Conversion of the digitalized pixel positions onto the 5-km-resolution grid used by HIRHYLTAD



OBSERVATION *+ digitization* ***SIMULATION*** *with HIRHYLTAD* ***VALIDATION*** *with area and direction indices*

VALIDATION
- Review of the NOAA Smoke Forecasting System (SFS) **area indices**
- New **direction indices**

Figure of Merit in Space (SFS)

$$FMS=\frac{Aobs\cap Afor}{Aobs\cup Afor}=\frac{Aint}{Aobs+Afor-Aint}\quad\Rightarrow\quad 1-FMS$$

Error version

Plume Overlay Area Hit index

$$POAH=\frac{2Aint}{Aobs+Afor}\geq FMS\quad\Rightarrow\quad POAE=1-\frac{2Aint}{Aobs+Afor}$$

Plume Mean Orientation Hit index

$$PMOH=1-\frac{|\overline{dir}_{obs}-\overline{dir}_{for}|}{180^o}\quad\Rightarrow\quad PMOE=\frac{|\overline{dir}_{obs}-\overline{dir}_{for}|}{180^o}$$

EXAMPLE 1
Single-source plume

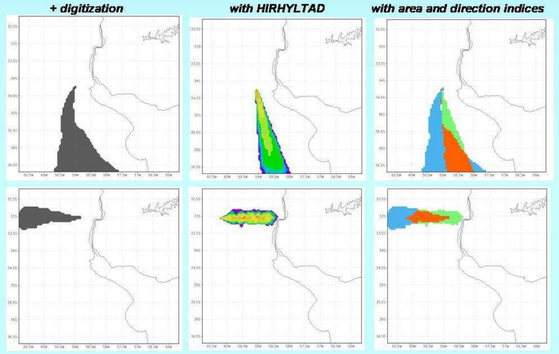
Error scores:

1-FMS = 66.56 %
POAE = 49.88%
PMOE = 4.34%

EXAMPLE 2
Multiple-source plume

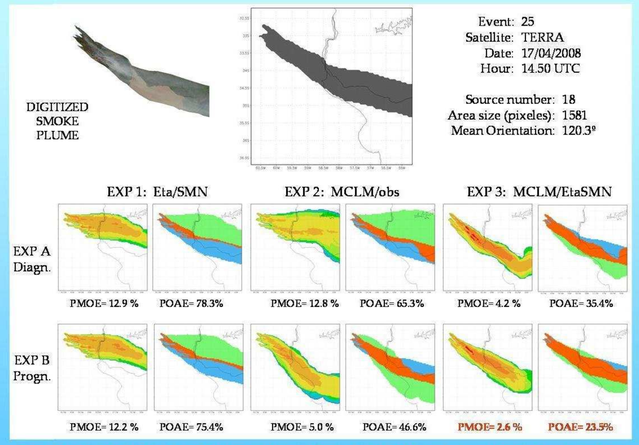
Error scores:

1-FMS = 71.85 %
POAE = 56.07%
PMOE = 96.52%



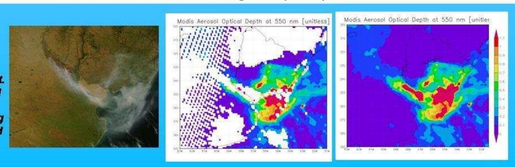
Reddish color in the HIRHYLTAD outputs is indicative of higher concentrations. Overlay, no detection and false detection areas are depicted in red, blue and green colors, respectively. Scores for area and direction error indices are detailed on the left.

RESULTS AND DISCUSSION



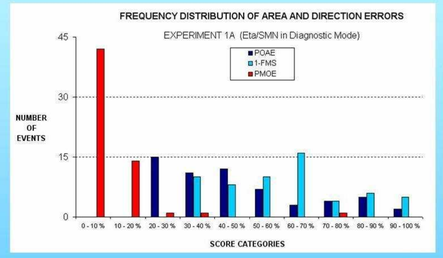
Graphical display of the validation for a selected event. Double-entry table showing smoke plume simulations from HIRHYLTAD (left) and area diagrams (right) for each of the 6 experiments. Interpretation of area colors as in the figure above. Below each pair of figures, area and direction error scores are detailed (in red color font: best performance).

Objective selection of events and validation with Aerosol Optical Thickness (AOT) derived from MODIS was NOT performed, after the results of a preliminary analysis. (Reason: low resolution and abundance of missing data pixels)



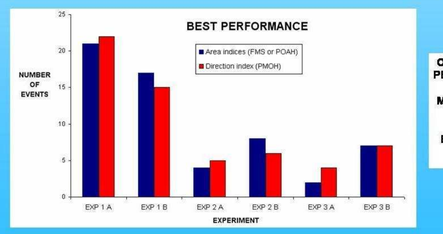
MODIS real-color image from TERRA on April 18, and its AOT derived product. On the second panel an algorithm for interpolating missing data pixels was used

Smoke events overview
- 59 analyzed events from a 45-day period (April 1 - May 15, 2008)
- 21 from TERRA and 38 from AQUA satellites
- 21 single-source and 38 multiple-source smoke plumes



DESIRABILITY OF DEFINING AN ALTERNATIVE AREA INDEX, AND A NEW DIRECTION INDEX:

LOWER ERROR SCORES



OVERALL BAD PERFORMANCE WITH MBLM MODEL

REASON: EXPERIMENT DESIGN

FACTORS THAT AFFECT ERRORS

	DEGREE OF INCIDENCE
- Meteorological Models	low
- Experiment Design	high
- Dispersion model	low
- Methodology	high