SMOKE PLUME FROM FIRE LAGRANGIAN SIMULATION AND VALIDATION USING GROUND-BASED LIDAR DATA

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Introduction

- In the current operational models, the plume rise is computed assuming an air parcel's rise based only on the buoyancy terms (Briggs, 1975).
- These assumptions can lead to big approximations. In fact, the plume is likely to reach the top of the boundary layer during the day and to partially penetrate above the temperature inversion layer at the top of it (Weil et al. 2002).

Methodology

- We propose to use the method suggested by Alessandrini et al. (2013) for the buoyant plume rise simulation based on the Lagrangian description of plume temperature and momentum.
- In previous works we tested our plume rise model against point source emission data from both laboratory experiments (Huq and Stewart, 1996; Contini et al., 2011; Weil et al. 2002) and field campaign (Hanna and Paine, 1987, 1989).

Turbulent velocities

We use a Lagrangian Stochastic Model which solves a Langevin equation (Thomson, 1987)

$$du_i = a_i(\mathrm{u}, \mathrm{x})dt + b_{ij}(\mathrm{x})dW_j(t)$$

The *scalar concentrations are calculated on a Eulerian fixed grid*

Plume rise

Each particle carries **two scalars or equivalent mass: temperature difference** and **momentum**

$$m_{T_i} = \frac{[T_{pinit} - T_a(H_s)]w_u S \Delta t}{N_p}; \quad m_{w_i} = \frac{[w_{pinit} - w_a(H_s)]w_u S \Delta t}{N_p}$$

Then air-plume temperatures difference and momentum of each cell at the time t_0 are calculated as:

$$\Delta T_c(t_0) = \frac{\Sigma_i^M m_{T_i}(t_0)}{V_c}; \quad \Delta w_c(t_0) = \frac{\Sigma_i^M m_{w_i}(t_0)}{V_c}$$

Plume rise II

- The air-plume temperatures difference of the cell at the time t_1 is obtained through the equation:

$$\Delta T_c(t_1) = \Delta T_c(t_0) + \Gamma(z_c) w_c(t_0) \Delta t - 0.0098 w_c(t_0) \Delta t$$

  where z_c is the cell height and $\Gamma(z_c)$ is the lapse rate of the ambient air at the cell height z_c.

- The vertical velocity of each cell is calculated through the temperature difference:

$$w_c(t_1) = w_c(t_0) + \frac{\Delta T_c}{\Delta T_c + T_a(z_c)} g \Delta t - \frac{0.5 C_D S w_c^2(t_0) \rho_a}{\rho_p V_c} \Delta t$$

Plume rise III

The new *equivalent masses* for temperature difference m_{T_i} and momentum m_{w_i} are computed for each particle following the method proposed by Chock and Winkler (1994):

$$m_{T_i}(t_1) = \frac{m_{T_i}(t_0)\Delta T_c(t_1)}{\Delta T_c(t_0)}; \quad m_{w_i}(t_1) = \frac{m_{w_i}(t_0) w_c(t_1)}{w_c(t_0)}$$

Then, the particles are moved by the stochastic (Langevin) model.

Fire field experiments

- August of 2013, multi-agency field experiment organized by the US Environmental Protection Agency (EPA)
- Designed to acquire the observational data necessary to improve the air quality models used by agricultural smoke managers in the northwestern United States.
- In this experiment, the **ground-based mobile elastic scanning lidar** and data-processing methodology, developed at the US Forest Service Missoula Fire Science Laboratory (FSL), have been used to study the plume dynamics and the optical properties of smoke particles over open biomass fires.

Plume height measurement

- The special data-processing methodology was applied to lidar observations to determine the heights of smoke plume columns and smoke layers and the temporal changes of the plume rise heights.
- During this experiment lidar measurements of plume rise heights for nine agricultural fires were obtained.
- The lidar measurements are being used to evaluate our plume rise model which could be used in several smoke management tools.

We present preliminary results regarding the application of the plume rise model to agricultural burning based on lidar measurements made in the vicinity of Nez Perce, Idaho, on August 19 and 20 and Walla Walla, Washington, on August 24, 2013.

Fires characteristics

FIRE	Date	Est. Ignit.	Lat	Lon	Area	Elevation
1	19/08/13	12:00 (PST)	46.20	-116.25	66 (ha)	1000 (m)
3	20/08/13	10:40 (PST)	46.20	-116.24	66 (ha)	1000 (m)
4	20/08/13	13:05 (PST)	46.20	-116.23	66 (ha)	1000 (m)
6	24/08/13	8:50 (PST)	46.24	-118.33	96 (ha)	397 (m)

Buoyancy flux determination

$F = Q \cdot \mathbf{0.00000258}$ (Pouliot et al., 2005)

where:

F = buoyancy flux (m^4/s^3)

Q = heat flux (BTU/hr)

Emissions

FIRE	Date	Buoyancy flux(m^4/s^2)	PM2.5 kg/s
1	19/08/13	3800	0.6678
3	20/08/13	5600	0.7467
4	20/08/13	9500	1.6422
6	24/08/13	7000	1.0122

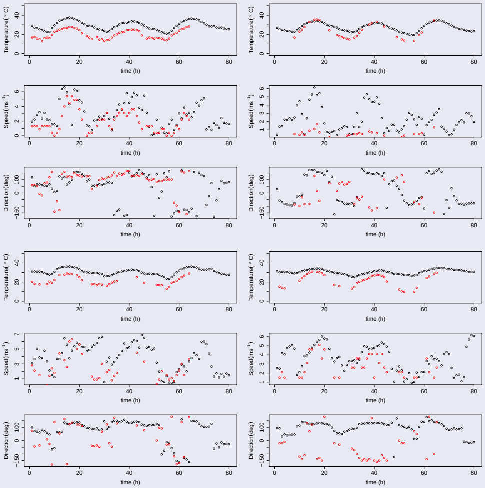
Model chain

- Meteorological fields: WRF (Skamarock et al, 2008)
- Turbulence and interpolated meteo fields: WRF to SPRAYWEB Interface (Bisignano et al, 2016; Tomasi, 2017)
- Dispersion: SPRAYWEB Lagrangian particle model (Tinarelli et al, 1994, 2000; Alessandrini and Ferrero, 2009)

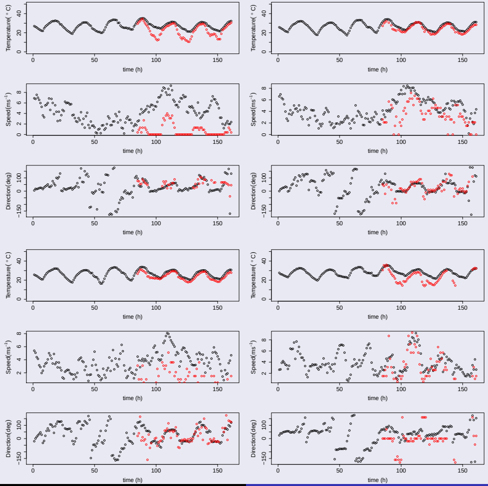
WRF setup

- from 2013-08-19 00:00:00 to 2013-08-26 00:00:00
- Two nested grids 3000x3000 m^2 and 1000x1000 m^2
- Horizontal grid points 61X61
- 38 vertical levels
- Buondary conditions $0.125^o/0.125^o$ ECMWF
- PBL model Mellor-Yamada-Janic

WRF simulation: comparison with measurements: trends (Idaho)



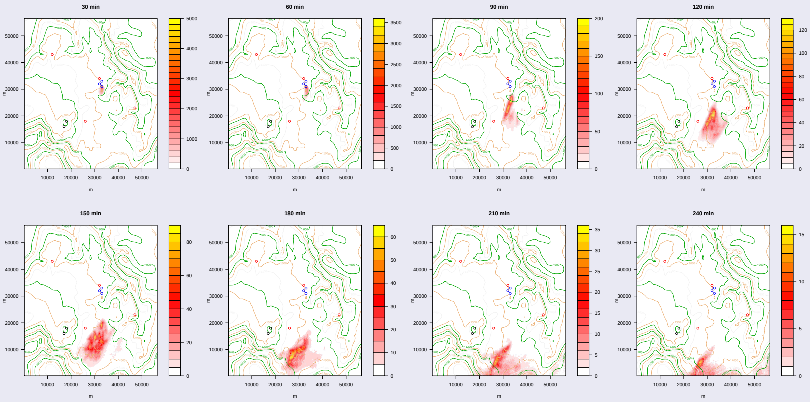
WRF simulation: comparison with measurements: trends (Walla Walla)



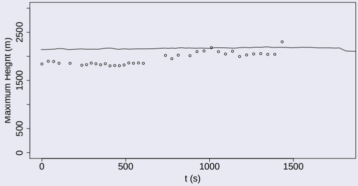
SPRAYWEB setup

- Domains size 60X60 km^2
- Time step 10s (substep 2 s)
- Hanna parameterisation for turbulence
- Particles 2000 every 2 s

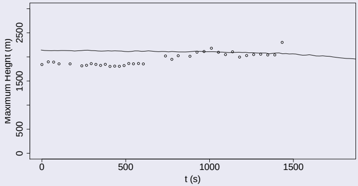
Idaho Fire 3: smoke dispersion



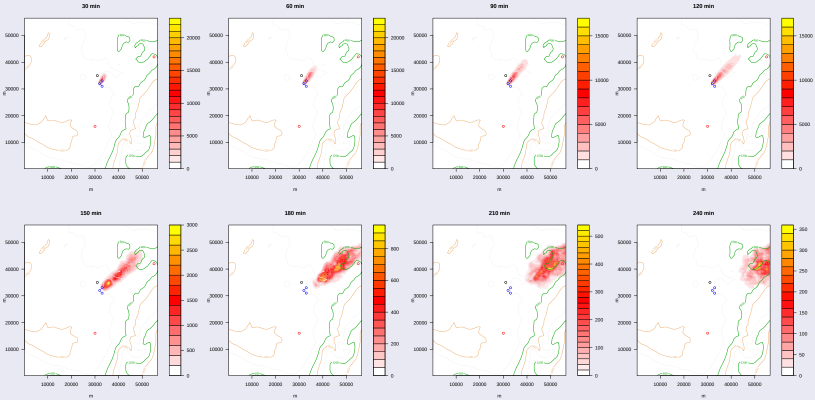
Mean plume heigh: model vs observations, Anfossi et al. (1993) plume rise scheme



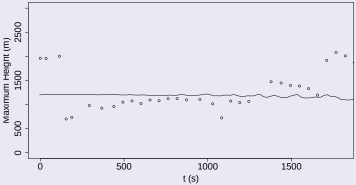
Mean plume heigh: model vs observations, New plume rise scheme



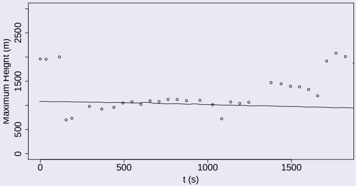
Walla Walla Fire 6: smoke dispersion



Mean plume heigh: model vs observations, Anfossi et al. (1993) plume rise scheme



Mean plume heigh: model vs observations, New plume rise scheme



Conclusions

1. We presented the results of smoke dispersion simulations performed using the WRF-SPRAYWEB modelling system
2. We compared the simulation results with lidar measurements of the plume height
3. The model is able to correctly reproduce the basic characteristics of a fire plume
4. Work in progress: meteo data assimilation, comparison of glc and aircraft measurements

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