UAFSMOKE: A WRF/CHEM SMOKE FORECASTING SYSTEM FOR ALASKA

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1: INTRODUCTION

Alaska wildfires have strong impact on air pollution on regional and even hemispheric scales. Alaska's climate favors annually recurring wildfires. Highly flammable material like dry tundra and leaves and needles at the floor of the boreal forests are well preserved during cold and dry seasons. As a result lightning induced fires are common during summers. Extreme fire seasons occurred in 2004 and 2005. The 2004 season was one of the warmest and driest summers on record. By the end of summer 2004 wildfires burned 6.6 millions of acres of mostly boreal forest, which broke the 1957 record for the most acres burned in a season. Particulate matter threatened human health for weeks. Local communities suffered through direct and indirect impact of wildfires. For example high fine particulate matter (PM2.5) concentration was measured in Fairbanks during the 2004 fire season, when 41 days were reported as unhealthy to hazardous; 16 (of the 41) days were classified as clearly hazardous to human health.

Hazardous smoke episodes occur almost every summer in Alaska communities. Hence the impact of smoke from wildfires on community health and safety is of key concern, and a strong need for a smoke forecast system for Alaska has been identified. System challenges are effective models for fuel burn, emissions and plume rise. Following we give an overview of the so-called UAFSmoke forecast system developed at the University of Alaska Fairbanks (UAF).

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2: SYSTEM DESCRIPTION

The UAFSmoke system runs autonomously on a regular scheduled time interval. System modules have been developed for acquisition of fire and emission source data, data pre-processing, WRF/Chem and output graphics production using NCL (Fig. 1).

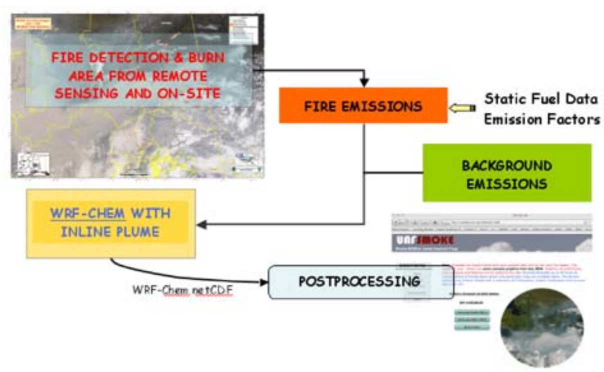

Fig. 1. UAFSmoke scheme of components

Fire information data

Main source data include fire location and extent, and fuel-type classification. Three sources of fire information data are available and suitable for UAFSmoke: (1) The University of Alaska Fairbanks (UAF) Geographic Information Network of Alaska (GINA) offers near real-time reception of MODIS data via a direct broadcast link. Fire locations and fire extent are derived from the MODIS thermal anomalies (MOD 14) product at a 1-km resolution up to 6 times a day (day and night) for Interior Alaska. The MOD 14 product is based on a dedicated large dynamic range 'fire' channel centered at 3.9 μm. MODIS allows detection of fires with extents down to 100 m^2 in area (depending on flaming temperature), however the fire area derived from the extracted 'hotspots' is subject to inaccuracy. (2) The 2nd fire information data source was developed at the University of Wisconsin- Madison: The experimental Wildfire Automated Biomass Burning Algorithm (WFABBA) is generating half-hourly updated fire data derived from the geostationary NOAA weather satellites GOES-11 and GOES-12. Data are typically available within 90 minutes of data acquisition. (3) High quality and detailed wildfire data are also available through the Alaska Interagency Coordination Center (AICC), which has been established as an inter-agency service compiling fire information mainly from expertsl involved in wildfire management or suppression. Currently UAFSmoke system uses a direct AICC online data transfer and the GINA fire products to obtain updated fire information in high resolution. Fire spread in between the update cycles (1 day) is neglected herein.

Emissions

Wildfire emissions depend on the fuel-type, loading, moisture, and fire intensity. A straightforward approach to estimate emissions E from a certain fire compound i from biomass burning has been described by Wiedinmyer et al. (2006) according to:

$$E_i = a * b * CE * e_i, \quad (1)$$

with a the burning area and b the fuel loading. The combustion efficiency CE depends on the tree coverage, while the emission factor e_i and the fuel load can be derived from a land cover classification.

Alaska's fuel types consist mainly of boreal vegetation characterized by grassland, shrub, black spruce forests (with tree heights of typically less than 10 meters) and birch forests. Wide areas of the forest floor show extensive layering development, and are covered by live and dead bole branches. Tree density decreases to the North; -shrubs and hardy tundra vegetation such as lichen is the main vegetation characterizing the Arctic. The Global Land Cover Dataset for 2000 (GLC2000) is used for vegetation classification. Wiedinmyer et al. (2006) have referred total fuel load to GLC2000 data. Emission factors (e_i in *Equ.1* in gram species per kilogram dry matter burned) have to be assigned to each smoke constituent and depend on the composition of the fuel. For biomass burning the emission factors depend predominantly on the physical and chemical properties of the combustion process, and may vary significantly for different stages of a fire from ignition, to flaming and to smoldering. Experimental setup is very difficult to distinguish emissions from the different fire stages. However corresponding uncertainty in emission factors is limited, since specific fuel composition and structure or GLC2000 land cover show typical burning characteristics with characteristic ratios between flaming and smoldering combustion. Andrae and Merlet (2001) compiled emission factors for 110 chemical species from fires in different vegetation types and from numerous fire emission experiments. Emission factors have been derived with good accuracy for the carbon species (i.e. CO_2, CO, CH_4) emitted from fires, however emission factors may include high uncertainty for species where only few measurements exist in the literature.

WRF/Chem with inline plume model

WRF-Chem has been recognized as an ideal tool to investigate dispersion of atmospheric pollutants such as wildfire smoke, since it predicts trace gas and particulate dynamics inline with the meteorological fields of WRF and allows for full interaction of chemistry and weather (Grell et al., 2005). In addition a one-dimensional fire plume model (Latham, 1994) has been coupled inline with WRF/Chem (current version WRF/Chem 3.1), which is a further major step forward in modeling atmospheric effects of wildfires. Typically we observe a strong temperature gradient in the extended atmospheric boundary layer above wildfires. Plume dynamics depend strongly on initial buoyancy and turbulent mixing of plume-ambient air with fire emissions (Freitas et al., 2006). The plume model inline in WRF/Chem eliminates inaccuracies due to previously necessary parameterization in order to consider small-scale plume dynamics in the significant larger scale of the numerical weather model.

UAFSmoke runs include anthropogenic and sea salt emission data, smoke fine particulate (PM2.5 and PM10), dust, black carbon (BC), organic carbon (OC), SO_2 and Dimethylsulfide (DMS), as well as OH, O_2H_2, and NO_3 from the Goddard Global Ozone Chemistry Aerosol Radiation and Transport (GOCART) model, which has been implemented optionally into WRF/Chem.

3: EXPERIMENTAL NEAR-REAL TIME FORECASTS

An integrating smoke manager program or smokeman was developed to run the smoke forecast both in near real-time and for retrospective analysis. Smokeman manages the different stages such as automatic updates of current fire information, smoke emission model run, WPS preprocessing, WRF/Chem job submission and monitoring or scheduling using reservation mechanism on a supercomputer, data post processing, web portal updates and system update. The program is written in Python programming language and designed to be portable between systems that support PBS scheduling systems on supercomputers. The configuration is set up through editing an initialization file or namelist templates. Currently smokeman is scheduled to run every night at 3:00 am AKST.

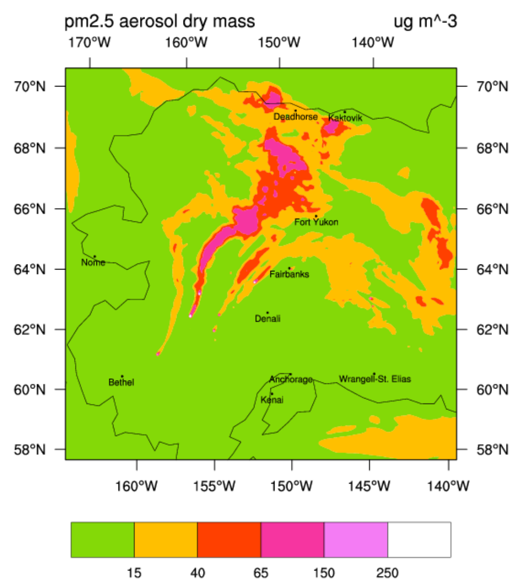

Fig. 2. Forecast example for PM 2.5 from 7th June 2009

UAFSmoke uses the GFS model for meteorological initial and boundary conditions. Once fire emissions as well as anthropogenic and biogenic background data are calculated by the ‘prepchem_sources’ routine, smokeman submits subsequently WRF/Chem version 3.1 model runs either in standard queue or using a previously reserved queue on the supercomputer. The run uses 96 Opteron cores on Arctic Region Supercomputing Center's Sun Opteron cluster "Midnight".

Currently UAFSmoke is configured with a single model domain in 5-kilometer resolution and 300 x 300 grid cells. The domain covers Alaska from 59º to 71º Northern latitude (without the Aleutians and the Alaska Southeast). Usually, every UAFSmoke run takes about 3 hours to complete in this configuration. Forecasts have been produced in an experimental near real-time mode once daily during the 2008 and 2009 fire seasons, updated forecast graphics are displayed on the UAFSmoke portal http://smoke.arsc.edu (compare example forecast Fig. 2). Preliminary verification of smoke forecasts with MODIS smoke plumes and PM2.5 data measured at the local air monitor station of the Fairbanks Northstar Borough showed promising UAFSmoke forecast quality.

4: SUMMARY

The UAFSmoke wildfire smoke forecast system has been developed to successfully predict the atmospheric dispersion of smoke downwind from Alaska wildfires. UAFSmoke system modules include detection of wildfire location and area from the Alaska Interagency Coordination Center (AICC) and additional sources from satellite remote sensing fire data such as the MODIS MOD14 product or the Wildfire Automated Biomass Burning Algorithm (WFABBA). The fire emissions are derived from above ground biomass fuel load data in one-kilometer resolution. WRF/Chem Version 3 with online plume dynamics represents the core of the UAFSmoke system. Besides wildfire emissions and NOAA's Global Forecast System meteorology, WRF/Chem initial and boundary conditions are updated with anthropogenic and biogenic data from various sources. System runs are performed at the Arctic Region Supercomputing Center's Sun Opteron cluster "Midnight". During the fire season UAFSmoke runs are presented at a dedicated web portal.

5: ACKNOWLEDGEMENTS

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6: REFERENCES

Andrae M.O. and P. Merlet, 2001: Emission of trace gases and aerosols from biomass burning, Global Biogeochemical Cycles 15 (2001) (4), pp. 955–966.

Grell, G.A., S.E. Peckham, R. Schmitz, S.A. McKeen, G. Frost, W.C. Skamarock, and B. Eder, 2005: Fully coupled "online" chemistry within the WRF model. Atmos. Environment, 39, 6957-6975.

Freitas, S.R., K.M. Longo, and M.O. Andreae, 2006: Impact of including the plume rise of vegetation fires in numerical simulations of associated atmospheric pollutants. Geophys. Res. Lett., 33, L17808, doi:10.1029/2006GL026608.

Latham, D., 1994: PLUMP: A one-dimensional plume predictor and cloud model for fire and smoke managers, General Technical Report INT-GTR-314, Intermountain Research Station, USDA Forest Service.

Wiedinmyer, C., B. Quayle, C. Geron, A. Belote, D. McKenzie, X. Zhang, S. O'Neill, K. Wynne, 2006: Estimating emissions from fires in North America for air quality modeling. Atmos. Environ., 40, 3419-3432.