



Impact of in situ burning on air quality

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maîtriser le risque |
pour un développement durable

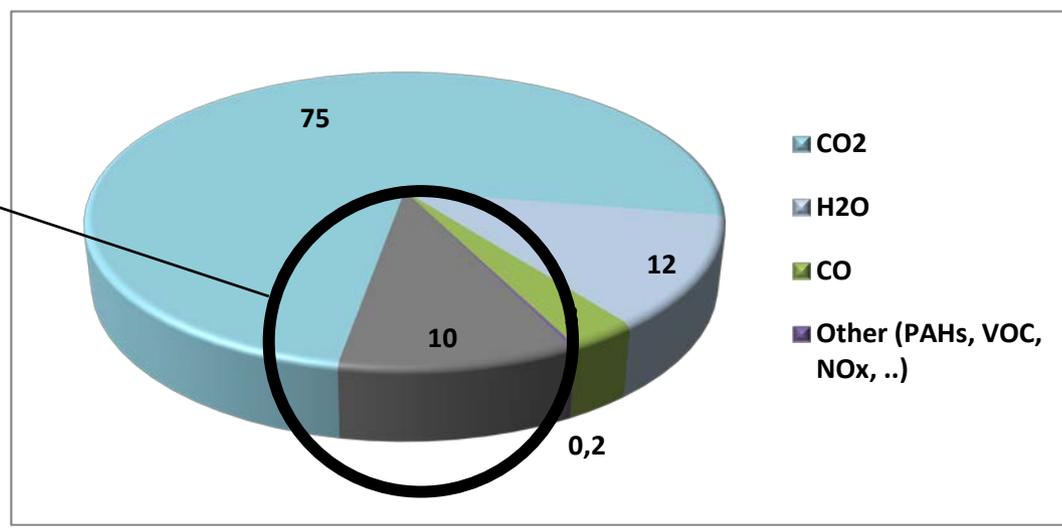
In situ burning: a major source of atmospheric pollutants

- Like industrial fires, burning flares or even forest fires, in situ burning generates emissions of massive quantities of atmospheric pollutants.
- The environmental and health impact will depend on the burn location, burn conditions and weather conditions but will always influence air quality.



What pollutants are emitted?

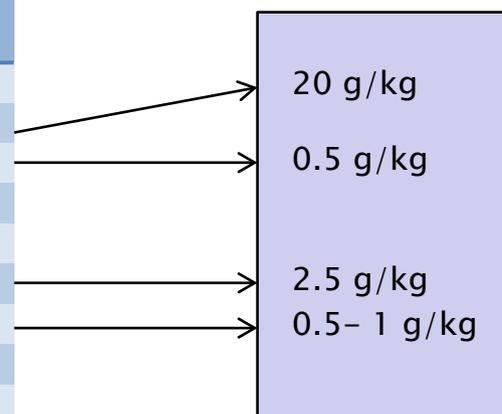
- Nitrogen oxides
- Particles (PM10 and PM2.5)
- Sulfur dioxide
- Hydrocarbons (VOC)
- Polycyclic aromatic hydrocarbons (PAHs)
- Dioxins



(adapted from SL Ross Environmental Research Ltd, 2010).

(adapted from Tennyson, 1994, Buist, 1999)

Constituent	Quantity Emitted ^b (g emission/kg oil burned)
Carbon Dioxide (CO ₂)	3000
Particulate Matter (PM)	50 – 200 ^{c,d}
Elemental Carbon (EC)	4 – 10 ^e
Organic Carbon (OC)	45 – 90 ^e
Carbon Monoxide (CO)	20 – 50
Nitrogen Oxides (NOx)	1
Sulfur Dioxide (SO ₂)	3 ^e
Volatile Organic Compounds (VOC)	5
Polynuclear Aromatic Hydrocarbons (PAH)	0.004



Emission factors associated with forest fires, from Turquetty et al, 2013

^aUpdated from Buist et al., 1994, based on the Kuwait pool fire (Allen and Ferek, 1993) and the NOBE data (Ross et al., 1996)

^bQuantities will vary with burn efficiency and composition of parent oil.

^cFor crude oils soot yield = 4 + 3 lg(fire diameter); yield in mass %, fire diameter in cm (Fraser et al., 1997)

^dEstimates published by Environment Canada are considerably lower, ca. 0.2% to 3% for crude oil (Fingas, 1996)

^efrom Ross et al., 1996

ISB versus other types of emissions

- Total PM10 emission during DWH: **40 Kton**
- Total PM10 emission in the USA: 600 Kton
- Buncefield PM10 emissions: 10 Kton

- Total black carbon released during DWH: **100-200 Ktons**
- Total elemental carbon: 8000 Kton during the Kuwait fires

- CO emissions during DWH: **10⁴ tons**
- CO emissions during the 2010 Russian forest fires: 19x10⁶–33 x10⁶ tons

EU Air quality standards (AQ Directive)

Pollutants	AQ Directive 2008/50/EC
PM10	50 $\mu\text{g}/\text{m}^3$ daily average not exceeded more than 35 times/year 40 $\mu\text{g}/\text{m}^3$ yearly average
PM2.5	Exposure index based on the daily average 25 $\mu\text{g}/\text{m}^3$ yearly average (20 $\mu\text{g}/\text{m}^3$ in 2020)
O3	120 $\mu\text{g}/\text{m}^3$ 8-hours average not exceeded more than 25 days/year
NO2	40 $\mu\text{g}/\text{m}^3$ yearly average 200 $\mu\text{g}/\text{m}^3$ hourly average not exceeded more than 18 times/year
SO2	350 $\mu\text{g}/\text{m}^3$, hourly average not exceeded more than 18 times/year 125 $\mu\text{g}/\text{m}^3$ daily average not exceeded more than 5 times/year
Lead (Pb)	0.5 $\mu\text{g}/\text{m}^3$ yearly average
Benzene (C6H6)	5 $\mu\text{g}/\text{m}^3$ yearly average
CO	10 mg/m^3 maximum 8-hours daily average

US Air quality standards (Clean Air Act)

Pollutant	Primary/Secondary	Averaging time	Level	Form
Carbon Monoxide (CO)	Primary	8 hour	9 ppm	Not to be exceeded more than once per year
		1 hour	35 ppm	
Lead (Pb)	Primary and secondary	Rolling 3 month average	0.15 $\mu\text{g m}^{-3}$ (a)	Not to be exceeded
Nitrogen Dioxide (NO ₂)	Primary	1 hour	100 ppb	98th percentile, averaged over 3 years
	Primary and secondary	1 year	53 ppb (b)	Annual Mean
Ozone (O ₃)	Primary and secondary	8 hour	75 ppb (c)	Annual fourth-highest daily maximum 8-hr concentration, averaged over 3 years
Particles PM _{2.5}	Primary	1 year	12 $\mu\text{g m}^{-3}$	Annual mean, averaged over 3 years
	secondary		15 $\mu\text{g m}^{-3}$	
	Primary and secondary	24 hours	35 $\mu\text{g m}^{-3}$	98th percentile, averaged over 3 years
Particles PM ₁₀	Primary and secondary	24 hours	150 $\mu\text{g m}^{-3}$	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO ₂)	Primary	1 hour	75 ppb (d)	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
	Secondary	3 hours	0.5 ppm	Not to be exceeded more than once per year

Health protection

Welfare protection

(a) Final rule signed October 15, 2008. The 1978 lead standard (1.5 $\mu\text{g}/\text{m}^3$ as a quarterly average) remains in effect until one year after an area is designated for the 2008 standard, except that in areas designated nonattainment for the 1978, the 1978 standard remains in effect until implementation plans to attain or maintain the 2008 standard are approved.

(b) The official level of the annual NO₂ standard is 0.053 ppm, equal to 53 ppb, which is shown here for the purpose of clearer comparison to the 1-hour standard.

(c) Final rule signed March 12, 2008. The 1997 ozone standard (0.08 ppm, annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years) and related implementation rules remain in place. In 1997, EPA revoked the 1-hour ozone standard (0.12 ppm, not to be exceeded more than once per year) in all areas, although some areas have continued obligations under that standard ("anti-backsliding"). The 1-hour ozone standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is less than or equal to 1.

(d) Final rule signed June 2, 2010. The 1971 annual and 24-hour SO₂ standards were revoked in that same rulemaking. However, these standards remain in effect until one year after an area is designated for the 2010 standard, except in areas designated nonattainment for the 1971 standards, where the 1971 standards remain in effect until implementation plans to attain or maintain the 2010 standard are approved.

Assessing the health impact of in situ burning

- Criterion generally used: compliance with air quality standards, in particular for particles (PM10 and PM2.5)
- Need to assess the impact of the plume on the concentrations of atmospheric pollutants in potentially affected areas to restrict population exposure
- Possibility of implementing measurement programmes to monitor air quality during operations
- Use of models to predict the effects and "safety" distances. Example: table based on simulations using ALOFT software

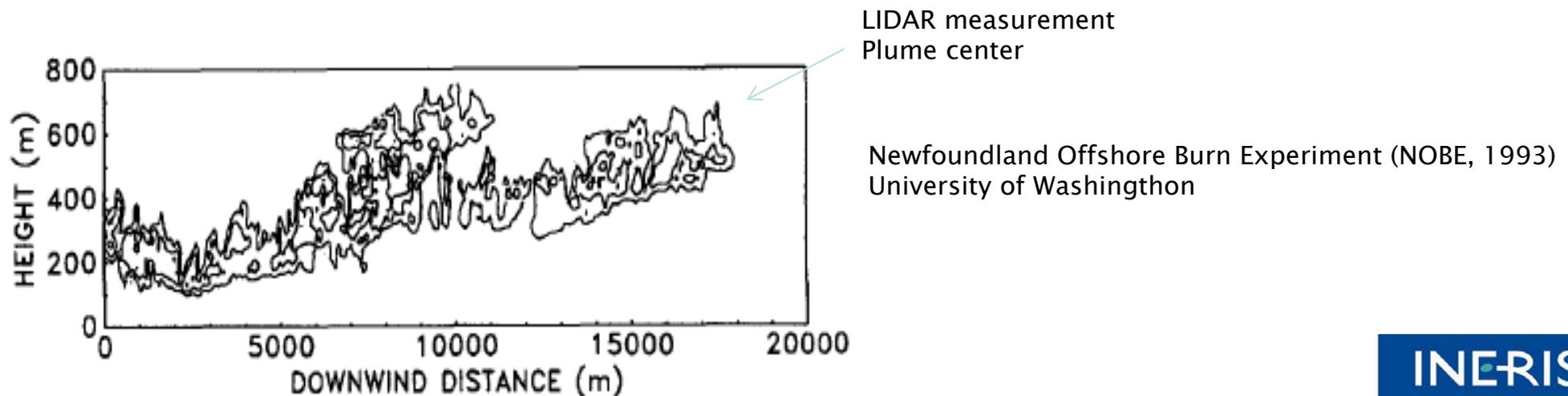
Location of Fire	Green Zone	Yellow Zone	Red Zone
Flat terrain on land	>3 miles	1 to 3 miles	<1 mile
Water <3 miles from shore			
Water >3 miles from shore	>1 mile	not applicable	<1 mile

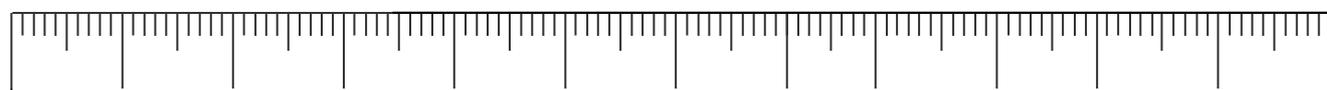
1 mile = 1.6 km

Safety distance between burns and downwind populations, according to the ARRT (Alaska Regional Response Team) guide

Marine conditions for atmospheric dispersion

- Atmospheric dispersion is driven by the nature of the surface. Sea surface implies different dispersion conditions compared to soils
 - Lower boundary layer heights (more stable conditions), the sea surface temperature being lower than the temperature in the air
 - Stable conditions when burning
 - High relative humidity
 - Presence of sea salts (potential interactions but not studied so far)
 - Sea temperature drives the air temperature (min temperature in March, max in September)
- In certain areas (Arctic region) the temperature of the sea can lead to high gradients with the atmosphere, with very low boundary layer heights





Sensitivity study

Scenario #1: Alaska coast (60°48'36"N / 146°52'23"W)

Date of spill: 09/11/2014 07:30:00

Water temperature: 8°C

Scenario #2: Gulf of Mexico (28°11'59"N / 88°47'59"W)

Date of spill: 14/09/2014 11:00:00

Water temperature: 20°C

Scenario #3: West African Coast (3° 01' N / 6° 58' E)

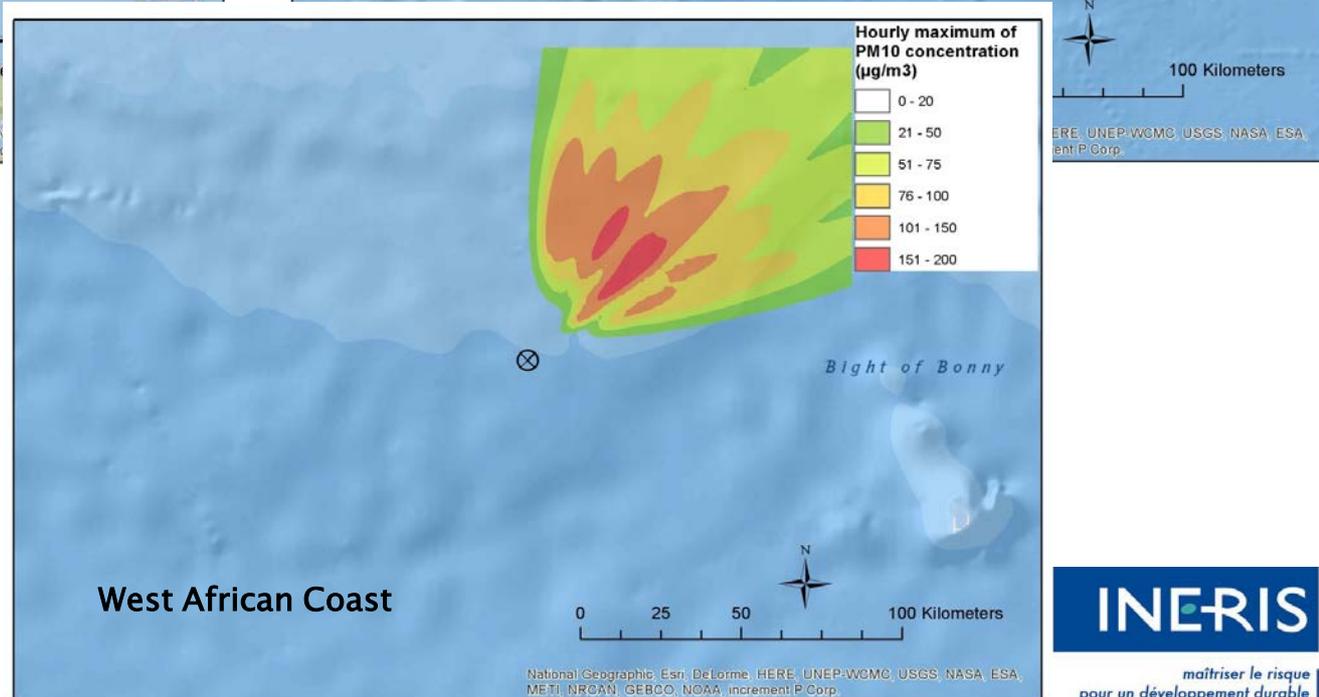
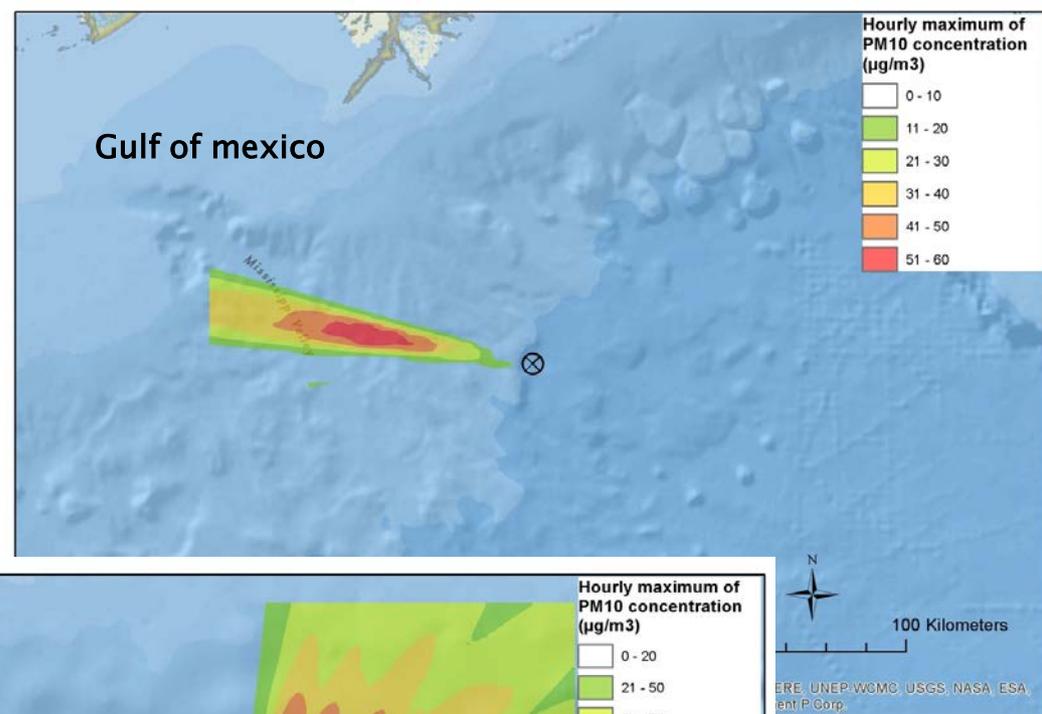
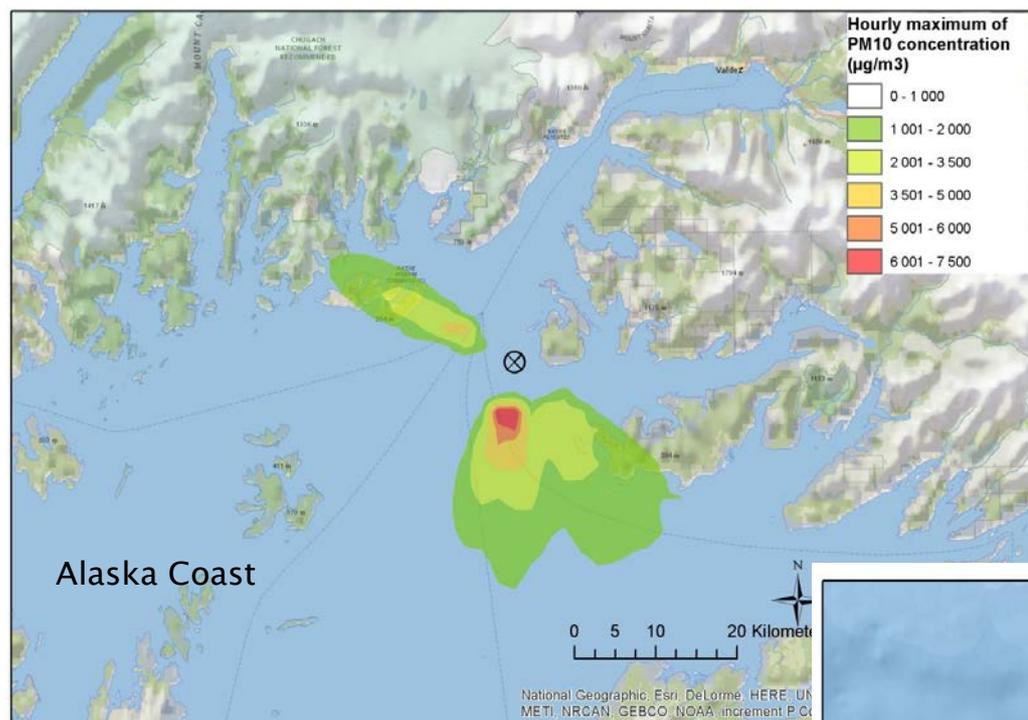
Date of spill: 09/11/2014 07:00:00

Water temperature: 28°C

7 days of simulation; same source term

Gaussian model: ADMS run by INERIS

Results: maximum hourly PM10 concentrations



Analysis:

- A certain degree of variability in results, preventing us from confirming the validity of the safety distances tabulated by ARRT
- High sensitivity to weather conditions, precipitation and water temperature
- No simulation of chemical transformations, although:
 - Massive release of VOC can impact ozone concentrations downwind of the plume
 - For the same reason ISB can favour secondary organic aerosol formation, and therefore increase PM concentrations
 - Long range transport of pollutants in the plume is a main driver

Conclusions

- Relatively few in situ burning impact studies focusing on air quality: mainly implemented using simple models with a view to assessing impact distances.

Name	Type of study	Modelling tools	Reference
Deepwater Horizon (2010)	Risk assessment levels due to dioxine (PCDD/PCDF) emission	Plume model (AERMOD) + Regional study using HYSPLIT model in an eulerian/puff mode - plume rise computation from OBODM (Dumbauld et al. (1973) derivation of Briggs formula (1971), for large source)	Schaum et al., 2012
NOBE and Alaskan plume (Burning of emulsion test)	Trajectory and particle concentration simulation	LES particle model (ALOFT-FT and ALOFT-CT)	Mc Grattan et al., 1996
MOBILE Mesoscale experiment	Trajectory and particle concentration simulation	LES particle model (ALOFT-FT)	Walton et al., 1993
NOBE, ALASKA and MOBILE	Trajectory and particle concentration simulation	Sum - up of previous papers + comparison with CALPUFF	Mc Grattan et al., 2003
Coastal measurement in California and Gulf of Mexico	Simulation of emissions from offshore sources, not specific to in-situ burning.	Plume model + specific adaptation for over sea emission and coastal environment	Hanna et al., 1985

- However, it is difficult to quantify the impact of in situ burning on the environment without taking into account specific factors relating to the location, weather conditions, and even the type of substances burnt.
- Nevertheless, certain burn operations involving emission measurements provide new data.
 - Deepwater Horizon (DWH) oil spill: Middlebrook et al., 2011 predicted high Secondary Organic Aerosols along the coast
 - Impact of the evaporation of VOC on O₃ production (some papers)
- Potentially high impacts due to settling dust, soot (on the Arctic continent?), dioxins and PAHs due to their health impacts. Deposits at sea are low but may be significant on land where populations live.