NORTRIP model development during NORDUST

Bruce Rolstad Denby
Background

• The NORTRIP model is a road dust emission model used in Nordic countries to predict and study road dust emissions

• The model describes a number of processes in relation to dust, salt and water/ice/snow on the road surface resulting in road dust emissions

• One of the aims of NORDUST was to provide experimental data to improve the model description
A coupled road dust and surface moisture model to predict non-exhaust road traffic induced particle emissions (NORTrip). Part 1: Road dust loading and suspension modelling.


Road salt emissions: A comparison of measurements and modelling using the NORTIP road dust emission model.

Model processes addressed during NORDUST

• Vehicle spray removal of water, salt and dust (MORS2)
• Size fractions of PM$_{200}$, PM$_{10}$ and PM$_{2.5}$
• Road dust cleaning efficiency
• Crushing of sand to generate PM$_{10}$
• Conceptual model of road dust suspension
• Linking mobile measurements to road dust loading
Vehicle spray

- Vehicle spray on higher speed trafficked roads is a major sink for water and also road dust/salt. This is one of the reasons high speed roads are cleaner than low speed ones.

- Vehicle spray is strongly dependent on speed but little quantifiable information is available

- MORS2 data has been used, spray deposition measurements, to provide spray parameters for water

- In NORTTRIP vehicle spray is parameterised using a speed dependent quadratic power law

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Water</th>
<th>Snow</th>
<th>Ice</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{0,\text{spray}}$ (veh$^{-1}$) (he)</td>
<td>7.80E-04</td>
<td>7.80E-05</td>
<td>7.80E-06</td>
</tr>
<tr>
<td>$f_{0,\text{spray}}$ (veh$^{-1}$) (li)</td>
<td>1.30E-04</td>
<td>1.30E-05</td>
<td>1.30E-06</td>
</tr>
<tr>
<td>$V_{\text{rel,spray}}$ (km/hr)</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>$g_{\text{road,sprayable-min}}$ (mm)</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Power law factor for spray $a_{\text{spray}}$</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>$V_{\text{thresh,spray}}$ (km/hr)</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>
Size fractions in road dust, mobile measurements and ambient air

• PM$_{2.5}$/PM$_{10}$ ratios from various sampling methods and situations have been assessed to improve the model size distributions

• Suspended road dust in the field has relatively less fine particles than the measured road dust load or the measured road wear in the laboratory

• Why this discrepancy between the measurements/situations?
  • Aggregation of particles during suspension?
  • Lower efficiency of particle suspension for smaller particles?
  • Bias in measurement techniques?
  • On close inspection none of these explanations seem plausible
  • No conclusions have been drawn as yet
Road dust cleaning efficiency

• Before and after measurements of road dust have been used to assess the cleaning efficiency (fraction of road dust removed with each cleaning)
• Efficiency is highest for large dust loads and dependent on machine
• Redistribution of dust can lead to negative efficiencies
• A parameterisation based on the total available dust has been determined based on these data
• $f_{\text{cleaning}}$ will be a function of machine, method, road surface texture and history of the dust layer

$$E_{\text{cleaning}} = 100 \left(1 - \exp \left(- \frac{(DL_{180} - 20)}{f_{\text{cleaning}}} \right) \right)$$
Conceptual model of road dust suspension

• NORTrip has until now treated the road surface as one whole single surface
• Suspension is described as the fractional removal of all road dust with the passage of each vehicle from this whole surface
• There is a need to update these concepts to take into account the different parts of the road and to improve the suspension process description
  • Multiple track model describing the kerb and the ‘in’ and ‘between’ wheel tracks separately
  • Not all road dust is available for suspension so the concept ‘suspendable dust load’ must be introduced in the model
• NOTE: A large part of road dust emissions is direct emissions from wear. Should not over emphasize the role of road dust loading as the major source
Thank you for your attention

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Norwegian air quality forecasts using NORTTRIP and uEMEP

Bruce Rolstad Denby, Heiko Klein, Peter Wind, Matthieu Pommier, Alvaro Valdebenito, Michael Gauss, Hilde Fagerli
Ambition in Norway

• To provide a national air quality modelling system to support both local and national authorities in their air quality obligations

• The modelling system must cover the whole country but have sufficient detail to be useful at the local level

• The modelling system will be used for the following applications
  • Air quality forecasting
  • Short term air quality measures
  • Long term air quality planning
  • Providing information and awareness to the public
Content of this presentation

• Description of the model forecast system
• Emissions and road dust emissions used in the forecasts
• Example forecast maps
• Comparison to measurements for 2017
• Summary
Description of the model forecast system
What does the forecasting system deliver?

- 2-day hourly forecasts for all of Norway at 250 – 50 m for the pollutants $\text{PM}_{10}$, $\text{PM}_{2.5}$, $\text{NO}_2$ and $\text{O}_3$

- Local **source contribution** for each pollutant:
  - Traffic exhaust
  - Traffic non-exhaust (mostly road dust)
  - Shipping emissions (exhaust only)
  - Industrial emissions
  - Residential wood combustion
  - Other sources (mostly non-local contributions)

- Both forecasts and measurements are provided to the public through a web interface (luftkvalitet.miljostatus.no)
Overview of modelling in the forecast system

EMEP model for Europe

EMEP model for Norway

uEMEP

ECMWF global meteorology

CAMS European emissions

Local emissions

AROME meteorology

2.5 km

250 m

50 m
Emissions
Emissions in uEMEP

• uEMEP calculates the most important emissions sources in Norway for high resolution modelling. These are:
  • Traffic exhaust (per road segment)
  • Traffic non-exhaust (per road segment)
  • Shipping emissions (250 m grid)
  • Residential wood burning emissions (250 m)
  • Industrial emissions (per industry)

• All other source sector contributions are calculated on the larger scale using EMEP
Traffic data and emissions

- Road traffic and road network data is taken from the road authorities database for state roads (NVDB) and from a traffic model from SSB for municipal roads.
- In all 720,000 road segments are used containing 8 million individual road sublinks.
- NO\textsubscript{x} and exhaust particle emission factors are set everywhere to the national average, based on total road traffic emissions for Norway (SSB).
- The NORTTRIP model is used for all roads to calculate road dust emissions.
- Studded tyre share is derived from ~200 counting sites across the country (SVV) and distributed to each municipality.
- One single time profile for all traffic is currently used.
- Most emissions within tunnels exit at tunnel portals but some are deposited within the tunnels.
Road dust emissions

- PM emissions from road, tyre and brake wear, as well as road salt, are calculated using the NORTRIP road dust emission model.
- Calculates the road surface conditions and the accumulation of wear particles on the road surface.
- Calculates the direct emission from studded tyres and the suspension of the road dust particles.
- Salting and dust binding are included in the model description, but these activities are unknown.
- Salting activities are estimated based on a set of salting rules and snow ploughing automatically occurs above a snow depth threshold.
- No information on dust binding activities is available and it is not currently applied in the model.
Forecast maps

Direct link to web site
luftkvalitet.miljostatus.no

Direct link to maps
luftkvalitet.miljostatus.no/kart/59/10/5/aqi
Model region and measurements:

72 measurement stations in Norway

70 million model calculation points in Norway
Forecast maps PM$_{2.5}$: mostly from wood burning

20:00 08.02.2019
Forecast maps PM$_{10}$: mostly from road dust

18:00 05.03.2019
PM$_{10}$ comparison with measurements for 2017
Forecast validation PM$_{10}$ 2017: all 50 stations, weekly means
Forecast validation PM$_{10}$ 2017: mean all stations, daily mean time series

- **Spring peak in road dust**
- **Winter time wood burning**
- **Summer time underestimation**
- **Substantial non-local contribution**

Mean all stations

- Non local
- Traffic exhaust
- Traffic dust
- Local shipping
- Local heating
- Local industry
- Modelled
- Observed

$R^2 = 0.56$ $FE = -13\%$
Forecast validation PM$_{10}$ 2017: Annual mean source contributions at each station

Mean concentration at stations PM$_{10}$ 20170101-20171231

- Non local: 51.5%
- Traffic exhaust: 4.4%
- Traffic dust: 28.4%
- Local shipping: 0.2%
- Local heating: 15.2%
- Local industry: 0.3%
Forecast validation PM$_{10}$ 2017:
Number of days exceeding 50 µg/m$^3$ at each station
Forecast validation PM$_{10}$ 2017: daily and annual mean scatter plots

Scatter plot PM$_{10}$ daily mean 20170101-20171231

- $r^2 = 0.28$
- RMSE = 10.7 ($\mu$g/m$^3$)
- FB = -12.2 (%)
- FAC2 = 71.4 (%)
- OBS = 14.6 ($\mu$g/m$^3$)
- MOD = 12.9 ($\mu$g/m$^3$)

Mean concentration at stations PM$_{10}$ 20170101-20171231

- $r^2 = 0.30$
- RMSE = 3.7 ($\mu$g/m$^3$)
- FB = -11.1 (%)
- FAC2 = 100.0 (%)
- OBS = 14.5 ($\mu$g/m$^3$)
- MOD = 13.0 ($\mu$g/m$^3$)
Main conclusions from the comparison

- High resolution modelling is necessary to properly capture the spatial variation seen in both NO₂ and PM measurements
- There are still errors in traffic data and some stations reflect this

- Annual mean PM₁₀ is well represented in the model (bias = -12% and NRMSE= 25%) but the number of exceedance days is much more uncertain

- Spring time PM₁₀ from road dust is well modelled but the individual timing of episodes is not always correct
- PM₁₀ and PM₂.₅ from wood burning is well represented in the model
- PM₁₀ and PM₂.₅ are both underestimated in the summer
Thank you for your attention

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Additional slides
Forecast maps NO$_2$: mostly from traffic

20:00 08.02.2019
Forecast validation NO$_2$ 2017: mean all stations, daily mean time series

\[ R^2 = 0.67 \text{ FB} = -11\% \]
Forecast validation NO$_2$ 2017: daily and annual mean scatter plots

Scatter plot NO$_2$ daily mean 20170101-20171231

- $r^2 = 0.55$
- RMSE = 12.3 ($\mu$g/m$^3$)
- FB = -14.0 (%)
- FAC2 = 82.8 (%)
- OBS = 24.7 ($\mu$g/m$^3$)
- MOD = 21.4 ($\mu$g/m$^3$)

Mean concentration at stations NO$_2$ 20170101-20171231

- $r^2 = 0.75$
- RMSE = 5.5 ($\mu$g/m$^3$)
- FB = -14.5 (%)
- FAC2 = 100.0 (%)
- OBS = 24.5 ($\mu$g/m$^3$)
- MOD = 21.2 ($\mu$g/m$^3$)
Summary

• uEMEP extends the modelling capabilities of the EMEP model from global scales down to very local scales
• It is now implemented in Norway for air quality forecasting and verified against all available measurement data
• The comparison with measurements is good but not perfect, in Norway we lack full knowledge of emissions
• It can be implemented in other regions as well but it does require a high level of detail in emission and/or proxy emission data
• Development will continue and application regions will be extended
What is needed in an air quality forecast?

• Meteorology
  • Meteorological models provide forecasts required for the air quality model
  • Important are wind speed and direction, atmospheric stability, mixing height and precipitation
  • An air quality forecast is no better than the meteorology it uses!

• Emissions
  • Emissions from all known sources distributed in time and space
  • An air quality forecast is no better than the emissions it uses!

• An air quality model
  • Combines meteorology with emissions, transporting and dispersing these emissions
  • Includes chemical reactions and physical processes

• Interpretation and communication
The uEMEP model

- uEMEP is based on Gaussian plume modelling
- It places emissions into **sub-grids** (grids much smaller than the EMEP grid) and calculates each sub-grid emission contribution to all other sub-grids within a 10 x 10 km² region
- Smallest sub-grids are 50 m and the largest are 250 m
- A chemistry scheme is used only for NOₓ/O₃/NO₂
- uEMEP sub-grid concentrations are combined with EMEP grid concentrations in a special way to include local and non-local sources and avoid double counting
Some limitations

• uEMEP does not include buildings or other obstacles
• Meteorology is based on 2.5 km grids so details within these grids, e.g. due to variation in terrain, obstacles, are not represented
• Some emissions lack details, e.g. for industry stack heights and information for plume rise calculations are not available
• There are some significant uncertainties in the traffic data
• The uEMEP calculation region is limited to 10 x 10 km² (4 x 4 EMEP grids). For some industrial sources with large plumes this is not large enough
Model implementation
Model implementation: pollutants and sources

• uEMEP calculates the following pollutants
  • $\text{NO}_x$, $\text{NO}_2$, $\text{O}_3$, $\text{PM}_{10}$ and $\text{PM}_{2.5}$

• For each of these pollutants the fractional contribution of each source is calculated and provided
  • Traffic exhaust
  • Traffic non-exhaust (road dust)
  • Shipping
  • Residential wood burning
  • Industry
  • Non-local contribution (> 5 km)
Model implementation: tiling

• It is not possible, or necessary, to calculate concentrations at 50 m resolution for all of Norway
• uEMEP covers the entire country at a range of resolutions and uses tiling to achieve this
• 1864 separate tiles are used ranging in size from 40 x 40 km$^2$ to 5 x 5 km$^2$
• Grid resolution is highest (50 m) in urban areas within the 5 x 5 km$^2$ tiles
Overview

• The concentrations from 2017 have been calculated at all measurement sites for validation
• The calculations are made every day, and the first day of the forecast is used
• Pollutants shown are PM$_{10}$, PM$_{2.5}$ and NO$_2$
• Timeseries and scatter plots are shown
Example calculation: Tile 1619, 5 x 5 km², 50 m resolution
Emission data used in the EMEP model

• EMEP uses emissions from all sectors based on the European emissions inventories developed by CAMS (Copernicus Atmosphere Monitoring Service *)
• These emissions are provided at 7 x 7 km² for all of Europe, including Norway
• High resolution emissions for Norway (50 – 250 m) are not the same as the CAMS European emissions
• CAMS emissions are replaced in the EMEP calculations with the high resolution emissions for Norway after aggregation to 2.5 km
• The same high resolution emissions are then used in both the EMEP and uEMEP calculations

* https://atmosphere.copernicus.eu/
Shipping emissions

• AIS data (Automatic Identification System) is used for positional and movement information to determine exhaust emissions for shipping (kystverket.no)

• It is assumed that while AIS is turned on then the ships motors, or generators, are working. Emissions are determined from boat/engine type and speed

• Errors occur where land line electricity is available

• Heights of the emissions are not included in the AIS data

• Emissions are based on 2017 data. Monthly means and daily cycles each month are calculated on 250 m grids

https://kart.kystverket.no/
https://www.tu.no/artikler/bergen-havn-far-sin-forste-stikkontakt-for-skip/193813
Residential wood burning emissions

• New wood burning emission data has been provided by NILU (MetVed model)

• Uses a range of new data sources to better distribute wood burning emissions on a 250 m grid for all of Norway

• Uses ‘heating degree days’ (temperature dependency) to adjust the emissions on a daily basis

* Images supplied by Susana López-Aparicio, NILU
Industrial emissions

• Emission data for 300 industrial sites are available through Statistisk sentralbyrå (SSB) and Miljødirektoratet (www.norskeutslipp.no)
• Only total annual emissions are provided
• For PM only total particle emissions are provided (size unspecified)
• Lacking metadata (emission height, flow rate, temperature, detailed position of emission sources etc.) and temporal profiles
• Effective mission height set to 100 m for all industries
Terms and concepts

• ‘Grid’ is the calculation grid for EMEP (2.5 km for Norway)

• ‘Sub-grid’ is the uEMEP emission and concentration grid that is much smaller than the EMEP grid (250 – 50 m)

• ‘Local region’ is the area surrounding an uEMEP sub-grid where the uEMEP calculations are done (10 x 10 km²)

• ‘Non-local’ includes all EMEP modelled concentrations originating from emissions outside the local region and not included in uEMEP

• ‘Local’ means all uEMEP modelled concentrations from emissions within the ‘local region’
Forecast validation NO₂ 2017:
all stations, weekly means
Forecast validation PM$_{2.5}$ 2017: all stations, weekly means
Forecast validation $O_3$ 2017: all stations, weekly means
Forecast validation $O_3$ 2017: mean all stations, daily mean
The EMEP model

• The EMEP model is used to calculate concentrations for Europe (~ 10 km) and provides boundary conditions for the Norwegian calculation

• The EMEP model is applied over Norway (2.5 km) using the meteorological data from the Arome-MetCOOP model (the same model that provides forecast information for Yr)

• Within the EMEP model is a routine that calculates how much the emissions from each grid contribute to it and its surrounding grids (‘local fraction’)

• The ‘local fraction’ information allows us to place the high resolution uEMEP anywhere within EMEP by replacing the ‘local region’ EMEP grids with uEMEP ‘local’ sub-grids and avoid double counting of emissions
How uEMEP sub-grids are combined with EMEP grids

- uEMEP sub-grid (50 m)
- Non-local sub-grid with nonlocal EMEP
- EMEP grid (2.5 km)
- Local fraction EMEP
- Dispersion uEMEP sub-grid
Forecast validation PM$_{2.5}$ 2017: mean all stations, daily mean

$R^2 = 0.69$ FB = -15%
Forecast validation PM$_{2.5}$ 2017: daily and annual means

Scatter plot PM$_{2.5}$ daily mean 20170101-20171231

$\rho^2 = 0.44$
RMSE = 4.2 ($\mu g/m^3$)
FB = -14.4 (%)  
FAC2 = 78.4 (%)  
OBS = 7.0 ($\mu g/m^3$)  
MOD = 6.0 ($\mu g/m^3$)

Mean concentration at stations PM$_{2.5}$ 20170101-20171231

$\rho^2 = 0.39$
RMSE = 1.5 ($\mu g/m^3$)
FB = -12.8 (%)  
FAC2 = 100.0 (%)  
OBS = 6.9 ($\mu g/m^3$)  
MOD = 6.1 ($\mu g/m^3$)