An application of the RAMS-CALMET-CALPUFF modelling system to assess the long-term contribution to atmospheric pollution from a large industrial source in Tuscany

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Abstract: - The LaMMA consortium has carried out a work to assess the long-term contribution to atmospheric pollution due to one of the major industrial sources over Tuscany region, Italy, that is the ENEL electric power station, which is located close to the coastal town of Piombino. This goal has been achieved by means of the RAMS-CALMET-CALPUFF integrated modelling system, purposely developed by LaMMA. The system is based on the RAMS prognostic meteorological model, the CALMET diagnostic meteorological model, and the CALPUFF Lagrangian puff dispersion model.
A long-term application of RAMS-CALMET-CALPUFF has been performed over the whole Tuscany region on a 1-year time period with a 1-hour time step. The study area is 178x220 Km^2 wide, featuring a 2-Km spaced 89x110 computational grid.
Power station emission data have been provided by the IRSE regional emission inventory setup by the Tuscan Regional Government. In particular, main attention has been paid to the contribution to atmospheric pollution resulting from the PM_{10} primary component as well as SO_x and NO_x, which proved to be one of main precursors of PM_{10} secondary inorganic component.

Key-Words: - Dispersion models, Meteorological models, Industrial source, CALPUFF, RAMS, PM_{10}, SO_x, NO_x.

1 Introduction
The present study is aimed at assessing the atmospheric dispersion of pollutants emitted by one of the largest industrial sources over the Tuscany region, Italy. This is the ENEL electric power station, named "Torre del Sale", which is located close to the coastal town of Piombino.
The study domain is given by the whole Tuscany region, which has been modelled by means of a 2-Km spaced computational grid. The meteorological input is based on the RAMS prognostic model outputs, featuring a 4-Km resolution and covering a 1-year time period with a 1-hour time step. Therefore, the CALMET diagnostic meteorological model has been setup over the domain and later applied in a long-term mode to suitably downscale the RAMS meteorological fields to the final resolution of 2 Km. The ultimate application of the CALPUFF dispersion model allowed the estimation of concentrations of Sulphur Dioxide (SO_2), Nitrogen Oxides (NO_x), particulate matter (PM_{10}), SO_4, NO_3 and HNO_3. To calculate SO_2, NO_x, SO_4, NO_3 and HNO_3 concentrations the MESOPUFF2 chemical mechanism implemented into the CALPUFF model has been used, which is specifically conceived to treat slightly reactive secondary pollutants. On the contrary, PM_{10} has been treated as a mere inert species.
The CALPUFF model has been performed in a long-term mode on a 1-year time period with a 1-hour time step basing on the IRSE regional emission inventory setup by the Tuscan Regional Government. Eventually, model-calculated results concern a number of maps over the region of the annual mean concentrations of PM_{10}, SO_2, NO_x, HNO_3, NO_3 and SO_4.

2 Model description
The LaMMA consortium developed an integrated meteorological and diffusional modelling system [1] based on the CALMET [4] and CALPUFF [5] models, starting from the RAMS [6] meteorological model forecasting stored in a day-by-day updated archive built-up by LaMMA.
The implemented RAMS-CALMET-CALPUFF system is intended to be as a modelling tool to assess atmospheric pollution resulting from a wide

number of species and a various range of emission sources. The CALMET diagnostic model, suitably interfaced to RAMS thanks to a purposely developed interface, is able to provide the meteorological input to the CALPUFF Lagrangian puff dispersion model, which is designed to manage inert or slightly reactive pollutants. The working scheme of the modelling system is shown in Fig.1.

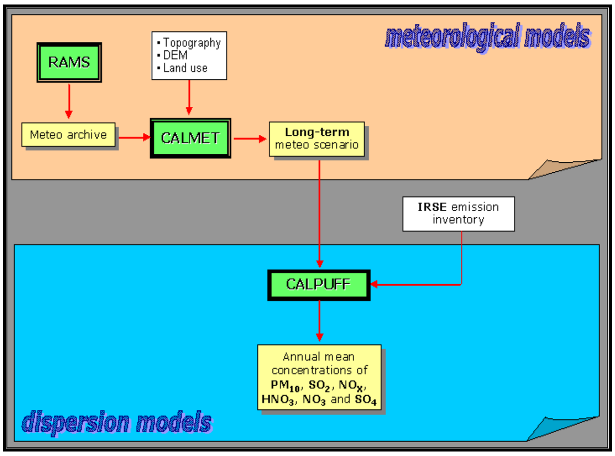

Fig.1: Architecture of the RAMS-CALMET-CALPUFF modelling system.

3 Application features

3.1 Overview

Fig.2 shows the map of the study domain, which almost covers the whole administrative boundaries of Tuscany region, Italy.

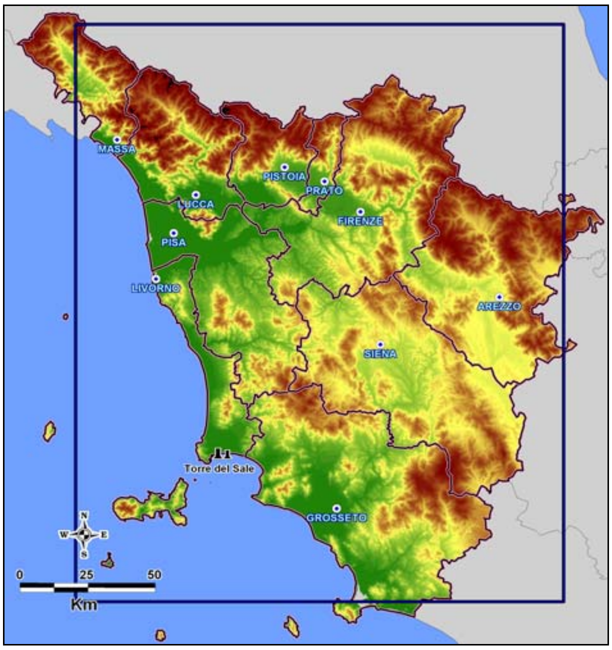

Fig.2: Map of spatial domain with industrial emission source highlighted.

In terms of model application features, the study area is 178x220 Km^2 wide, made of a 2-Km spaced 89x110 computational grid with 12 terrain-following vertical levels ranging from 10 to 2860 m. As far as geophysical data are concerned, both DEM and land-use data being used feature a space resolution of 2 Km. In particular, the "Corine Land Cover" European classification has been used for land-use data, with a total number of 15 categories. It is to be pointed out that both 2-Km spaced DEM and land-use data have been processed starting from 100-m spaced original data.

3.2 Meteorological input

The meteorological input of the present work was given by the RAMS prognostic model outputs, featuring a 4-Km resolution and covering a 1-year time period (year 2002) with a 1-hour time step. Therefore, the CALMET diagnostic meteorological model has been setup over the domain and later applied in a long-term mode all over the 2002 year to suitably downscale the RAMS meteorological fields to the final working resolution of 2 Km.

3.3 Emission data

Emission data have been provided by the IRSE regional emission inventory setup by the Tuscan Regional Government [7]. In the present work emissions due to one of the largest industrial sources in Tuscany have been taken into account. This is the ENEL electric power plant, named "Torre del Sale", which is located close to the town of Piombino (Fig. 2). In particular, such a power plant is supplied with two tall and wide stacks, whose elevation ranges to 195 m.
Tab.1 summarizes the parameters of two emitting stacks considered in the present work. Accordingly, in Tab.2 related emission rates of PM_{10}, SO_x and NO_x are reported.

Table 1: Emission source parameters of "Torre del Sale" power station.

Stack name	X-UTM (Km)	Y-UTM (Km)	Stack height (m)	Stack diameter (m)	Exit Flow (Nm^3/h)	Exit Temp. (K)
C1	630.858	4757.201	195	6.42	1600000	398
C2	630.858	4757.201	195	6.42	1600000	398

Table 2: Emission rates of "Torre del Sale" power station stacks.

Stack name	PM_{10} emission rate (g/s)	SO_x emission rate (g/s)	NO_x emission rate (g/s)
C1	12.4	156.4	79.1
C2	7.6	162.2	69.8

Emission rates provided by the IRSE emission inventory have been considered as constant all over the time period since no additional information is available regarding possible plant out-of-order or reduced activity periods. Of course, this brings to a general overestimation of modelled pollutant concentrations resulting from such a steady-state emission scenario. Moreover, inventory emission rates are intended to be as mere yearly estimations and do not result from real-time stacktip measurements. This proved to be another feature possibly causing model results to hardly simulate the actual air quality situation.

4 Analysis of results

4.1 Model-calculated outputs

Pollutants such as Sulphur Dioxide (SO_2), Nitrogen Oxides (NO_x), particulate matter (PM_{10}), SO_4, NO_3 and HNO_3 have been studied. To calculate SO_2, NO_x, SO_4, NO_3 and HNO_3 concentrations the MESOPUFF2 chemical mechanism implemented into the CALPUFF model has been used, which is specifically conceived to treat slightly reactive secondary pollutants. On the contrary, PM_{10} has been treated as a mere inert species.

Model-calculated results concern a number of maps of the annual mean concentrations of PM_{10}, SO_2, NO_x, HNO_3, NO_3 and SO_4. In particular, they have been calculated by averaging each of 8760 hourly gridded concentrations over Tuscany.

CALPUFF concentration output files have been processed by the CALPOST post-processor in order to perform the annual gridded concentration averages of each pollutant species. CALPOST-provided numerical outputs have been later processed by the SURFER [2] geographical mapping tool in order to achieve the concentration contours, which eventually have been imported into the MAPINFO [3] GIS-mapping software so that pollutant concentrations could be plotted over the study domain.

Figs. 3÷8 show the results performed by the RAMS-CALMET-CALPUFF modelling system applied in a long-term mode all over the 2002 year over the Tuscany region. In particular, the annual mean concentrations of PM_{10}, SO_2, NO_x, HNO_3, NO_3 and SO_4 are plotted, respectively.

As well as the territory orography, in the maps the location of two emitting stacks of the “Torre del Sale” electric power station is shown.

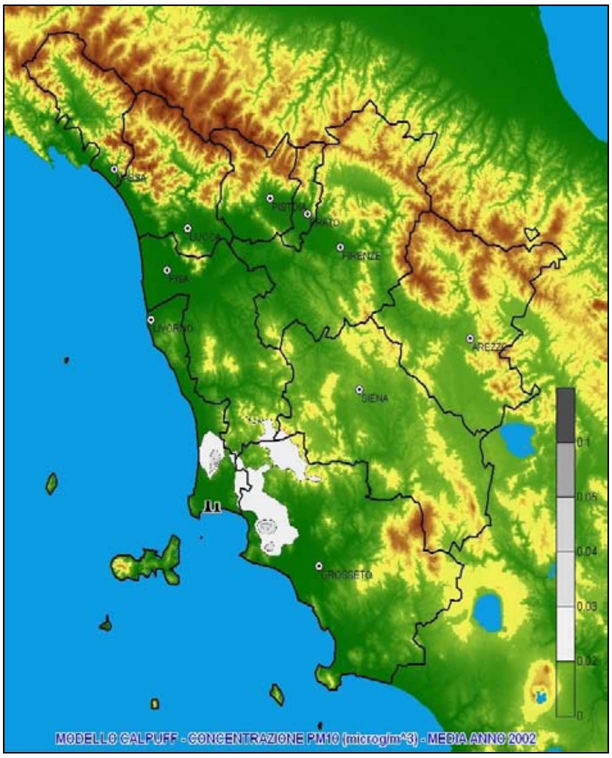

Fig.3: Map of PM_{10} annual mean concentrations ($\mu g/m^3$) calculated by CALPUFF (Jan. to Dec. 2002).

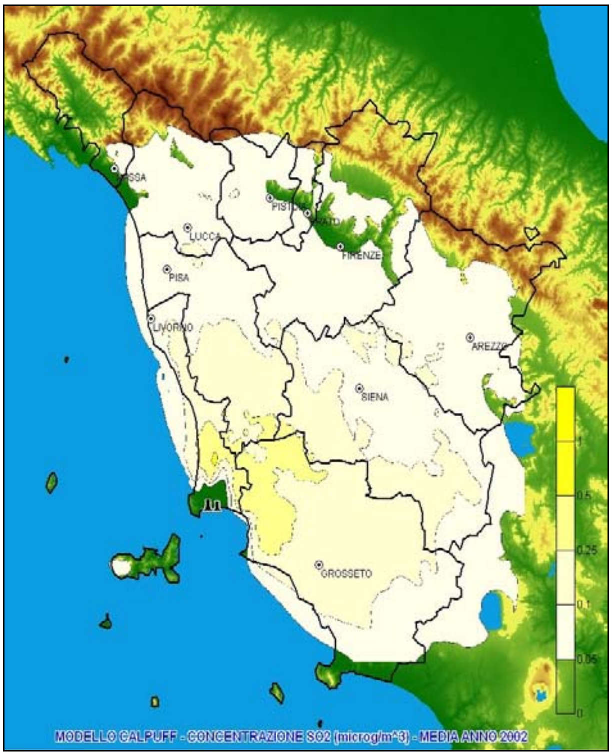

Fig.4: Map of SO_2 annual mean concentrations ($\mu g/m^3$) calculated by CALPUFF (Jan. to Dec. 2002).

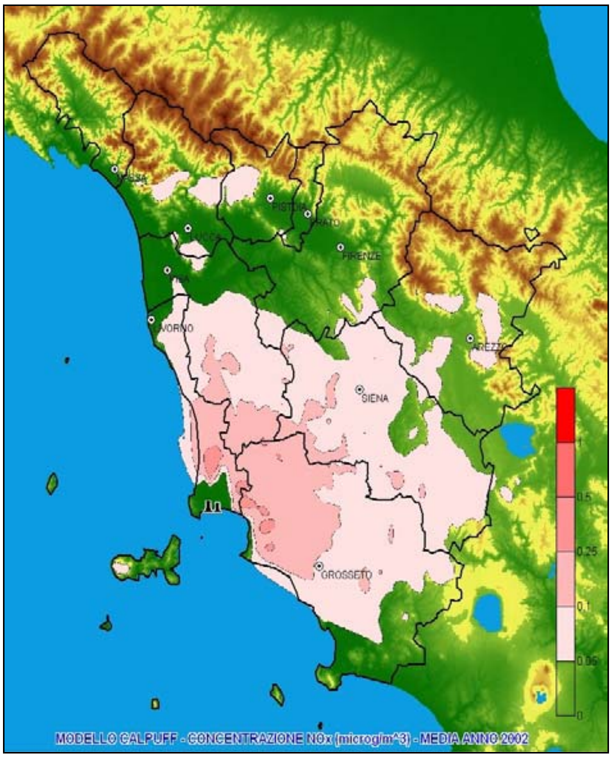

Fig.5: Map of NO_x annual mean concentrations ($\mu g/m^3$) calculated by CALPUFF (Jan. to Dec. 2002).

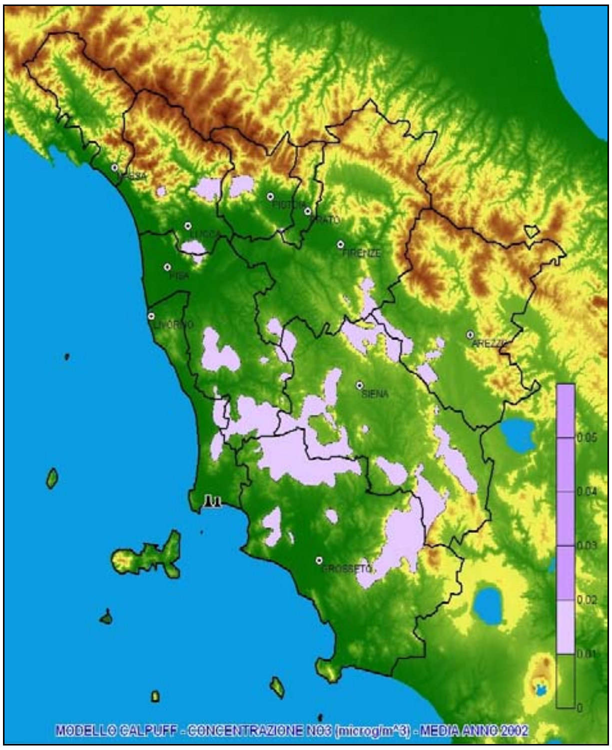

Fig.6: Map of NO_3 annual mean concentrations ($\mu g/m^3$) calculated by CALPUFF (Jan. to Dec. 2002).

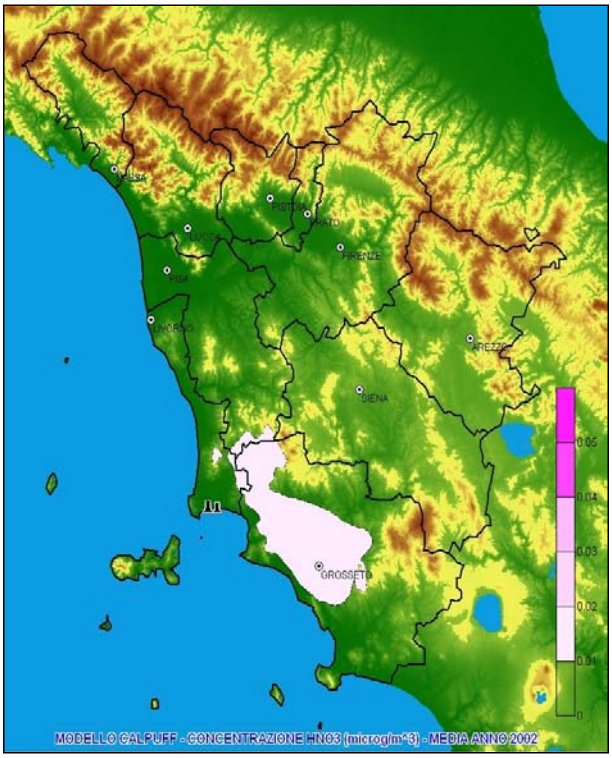

Fig.7: Map of HNO_3 annual mean concentrations ($\mu g/m^3$) calculated by CALPUFF (Jan. to Dec. 2002).

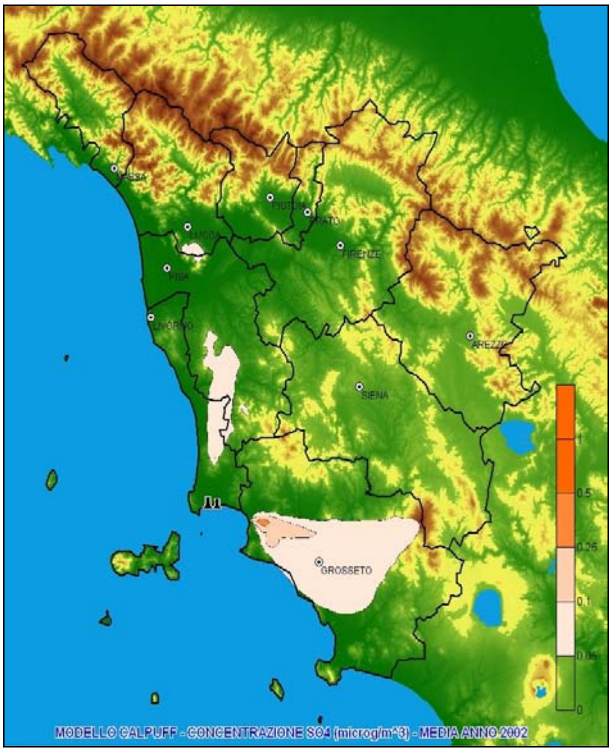

Fig.8: Map of SO_4 annual mean concentrations ($\mu g/m^3$) calculated by CALPUFF (Jan. to Dec. 2002).

4.2 Discussion

The analysis of annual mean concentration maps of SO_2 and NO_x (Figs. 4 and 5) shows that their related pollution involves almost the whole regional territory, particularly as far as the former is concerned (Fig. 4). This is clearly due to the amount of their emission rates, which are higher for SO_x (Tab. 2). As a matter of fact, only a small fraction of initial SO_x emissions is chemically converted by the MESOPUFF2 mechanism into SO_4 concentrations (Fig. 8), while the most is dispersed in the atmosphere in terms of SO_2 concentrations. As far as NO_x emissions are concerned, Figs. 5, 6 and 7 show that the NO_x rate which is chemically transformed into NO_3 and HNO_3 is definitely negligible, as shown by the very low concentration values of the latter (Figs. 6 and 7).

On the other hand, mean concentrations of inert-treated PM_{10} (Fig. 3) show a definitely less marked spatial distribution. Accordingly, this is accounted for PM_{10} emission rates, which are the lowest among all three emitted species (Tab. 2).

In any case, and dramatically for SO_2 and NO_x, it is to be pointed out that, on the contrary, concentration values are rather low in the proximity of emitting stacks. This is basically due to two features, that is the stacks geometrical and operative parameters on one hand, and the climatic conditions of the geographical area where they are located on the other hand.

As a matter of fact, both stacks are very toll, as they almost reach the elevation of 200 m (Tab. 1). In addition, gas exit temperature (about 400 K) is high as well, which enhances the plume rise effect. These two features cause pollutants dispersion to be highly effective, particularly towards the vertical direction, resulting in a long-range transport and therefore ground concentrations to occur very far from the emission source.

Moreover, the power station is located by the coastline, where strong winds typically blow for most of the time in a year. What's more, mixing height is typically lower across the sea-land interface, so that pollutants are generally emitted above the first thermal inversion layer and thus cannot fall down, which results in rather poor or negligible concentrations to the ground. This condition is known in literature as "lofting" effect.

Wind pattern shows a prevailing South-West to North-East bearing direction, that is winds blow from the seaside to the inland for most of the time. This causes the transport of polluted air masses to generally involve the inland inhabited areas.

By looking at the annual mean concentration maps of PM_{10}, SO_2 and NO_x (Figs. 3, 4 and 5), a general result is that their peak values proved to be rather low. However, particularly if considering SO_2 and NO_x concentration maps, the contribution to atmospheric pollution brought by the "Torre del Sale" power station emissions cannot be defined as negligible, particularly in terms of regional PM_{10} background concentrations, since SO_x and NO_x proved to be one of main precursors of PM_{10} secondary inorganic component.

5 Conclusions

In the present work the assessment of the long-term contribution to atmospheric pollution resulting from one of the largest industrial sources over the Tuscany region, Italy, has been carried out. This is the ENEL electric power station, named "Torre del Sale", which is located close to the coastal town of Piombino. This goal has been achieved by means of the RAMS-CALMET-CALPUFF integrated modelling system, purposely developed by LaMMA, which has been applied in a long-term mode over the whole Tuscany region on a 1-year time period with a 1-hour time step.

Main attention has been paid to the contribution to atmospheric pollution resulting from the PM_{10} primary component as well as SO_x and NO_x, which proved to be one of main precursors of PM_{10} secondary inorganic component.

The concentration maps of NO_x and particularly SO_2 showed their related pollution to involve almost the whole regional territory. This is due to the amount of their emission rates, which are higher for SO_x. Accordingly, annual mean concentrations of inert-treated PM_{10}, whose emission rates are the lowest, show a definitely less marked spatial distribution.

In any case, and particularly for SO_2 and NO_x, it is to be pointed out that, on the contrary, concentrations are rather low in the proximity of emitting stacks. This is basically due to two features, that is the stacks geometrical and operative parameters on one hand, and the climatic conditions of the geographical area where they are located on the other hand.

As a matter of fact, both stacks are very toll (195 m), as well as gas exit temperature is high (398 K). These two features enhance the plume rise effect and cause pollutants dispersion to be highly effective, resulting in a long-range transport and therefore ground concentrations to occur very far from the emission source.

Moreover, the power station is located by the coastline, where strong winds typically blow for most of the time. What's more, mixing height is typically lower across the sea-land interface, so

that pollutants are generally emitted above the first thermal inversion layer and thus cannot fall down, which results in rather poor or negligible concentrations to the ground ("lofting" effect).
Analyzing the CALPUFF-calculated annual mean concentrations of PM_{10}, SO_2 and NO_x, a general result is that their peak values proved to be rather low. However, particularly if considering SO_2 and NO_x concentration maps, the contribution to atmospheric pollution brought by the "Torre del Sale" power station emissions cannot be defined as negligible, particularly in terms of regional PM_{10} background concentrations, as SO_x and NO_x are one of main precursors of PM_{10} secondary inorganic component.
In conclusion, the RAMS-CALMET-CALPUFF modelling system proved to be a flexible and useful tool to assess the long-term atmospheric pollution contribution resulting from a wide number of species and a various range of emission sources, even when a large computational effort is needed. As a matter of fact, the system has been applied continuously through an 8760-hour time period all over the region (178x220 Km^2), that is by means of a 2-Km spaced 89x110 computational grid with 12 terrain-following vertical levels. However, model application could perform more reliable results in the future provided that hopefully emission data will be more accurate, particularly if time-varying and real-time observed emission rates will be available for each source within the regional emission inventory.

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