‘A critique of industrial air dispersion modelling in Trinidad & Tobago’

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ABSTRACT

Air dispersion modelling (ADM) was required by the Environmental Management Authority (EMA) of Trinidad & Tobago for an aluminium smelter complex, an iron and steel plant, and a chlor-alkali plant. This article critiques the outputs of the modelling. For the aluminium smelter complex, wind roses which were produced by the MM5 model, and then used in the CALPUFF ADM, underestimated calm periods 20-fold compared with actual observations. For the iron and steel plant and for the chlor-alkali plant, the ADMs (ISC3 and AERMOD) produced apparently unjustifiable bicycle-spoke patterns for airborne emission concentrations instead of concentric loops of iso-concentration around the source. It is concluded that the predictions of airborne emission concentrations were erroneous and that the Certificates of Environmental Clearance (CECs) for the plants must be withdrawn.

Keywords: air dispersion modelling, MM5, CALPUFF, ISC3, AERMOD, Trinidad & Tobago

1. INTRODUCTION

Fig. 1 shows the locations of three proposed plants: an aluminium smelter complex, an iron and steel plant, and a chlor-alkali plant. Each location has Receptors of Concern, such as existing human inhabitants, nearby.

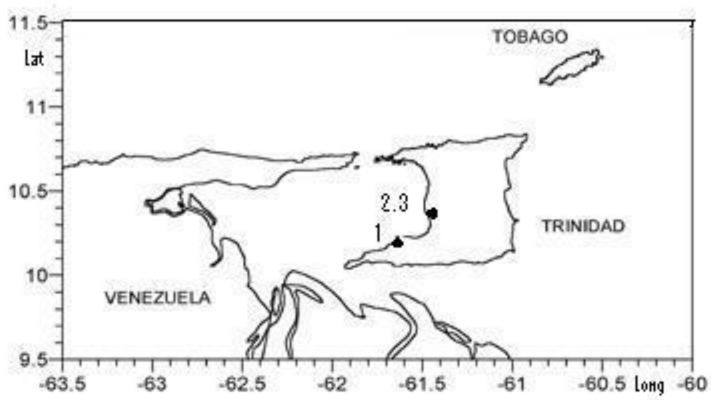

Fig. 1 Locations of proposed plants: 1 aluminium smelter complex, 2 iron and steel plant, 3 chlor-alkali plant.

Each plant required, amongst other things, air dispersion modelling (ADM) in order to be considered for a Certificate of Environmental Clearance (CEC) by the Environmental Management Authority (EMA) of Trinidad/Tobago. The materials in the present critique were presented to the EMA as input from the public, but were apparently ignored. It is therefore thought necessary to present the critique as a peer-reviewed journal article. It is believed that the material will also have relevance to other projects worldwide.

The concentration of an airborne pollutant at any position is determined by the amount of the pollutant emitted from each source, and the pattern of its dispersion. Models used to predict incidences of airborne emissions must adhere to principles of physics including conservation of mass, conservation of momentum, and conservation of energy (Builtjes, 2001).

It is necessary also to take into account the factors which affect wind movement, which include the topography of the land and the nature of the land surface (land use). The air behaviour which affects dispersion includes turbulence, boundary layers, and mixing. Turbulence is not a deterministic process; it is a probabilistic process, hence turbulence will be one of the factors contributing to plus-or-minus confidence limits. In addition to factors guiding the horizontal movement of airborne emissions, there are also vertical variations in atmospheric properties which affect the movement of such emissions.

Different commonly-used ADM models may differ markedly in output, e.g. the different outputs shown in Fig. 2 (Protonotariou et al., 2004).

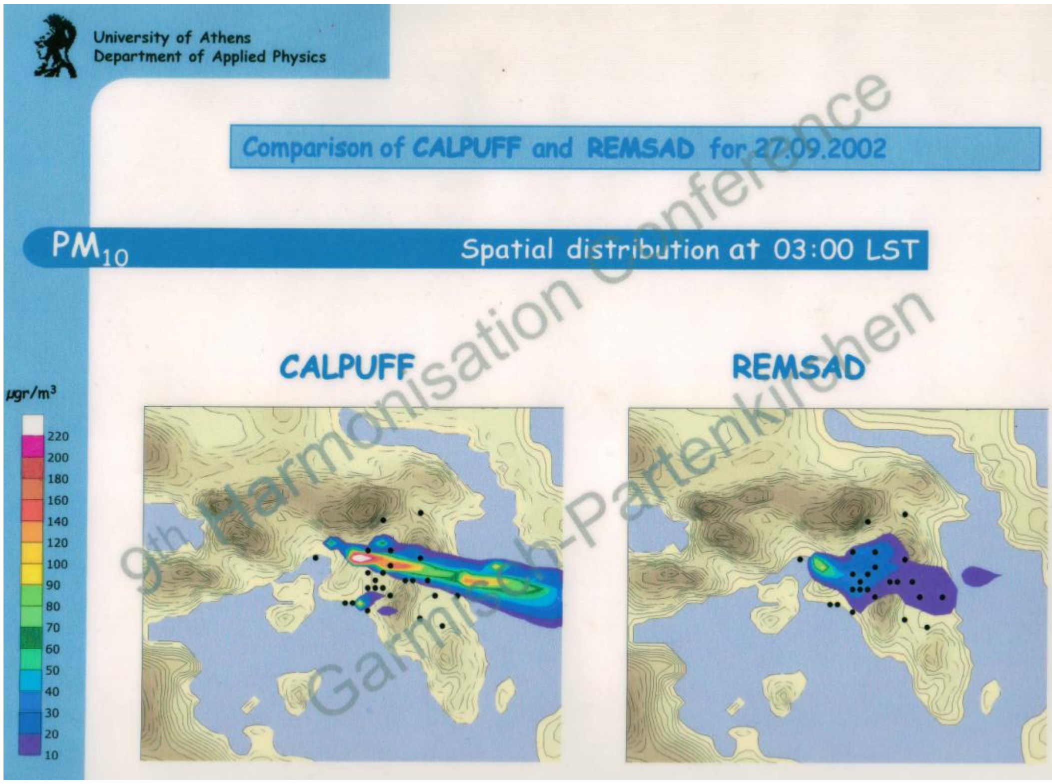

Fig. 2 Contrast in output of different commonly-used ADM models: comparison of CALPUFF and REMSAD predictions of PM10 (particulate matter <10 μm) concentrations for 27 September 2002, 03:00 LST (Protonotariou et al., 2004).

As stated by Kretzschmar (2001), a minimum requirement for an ADM model is that it is validated on past situations for which measured values are available.

The MM5 model was used by the proponents of the aluminium smelter complex in Trinidad/Tobago to predict meteorological conditions. Boucouvala et al. (2001) compared meteorological measurements with meteorological predictions made by the MM5 model. Statistics used included an index of agreement between observations and modelled values. The index of agreement (0 for no agreement, 1 for total agreement) for predicted and measured wind speed near the ground surface was typically about 0.7. MM5 predictions of maximum and minimum temperature were typically wrong by 2 to 4 degrees Celsius. Such disagreement implies considerable uncertainty in the meteorological predictions produced by MM5.

2. ALUMINIUM SMELTER COMPLEX

Alutrint Ltd proposes to set up and run a smelter complex at La Brea, Trinidad/Tobago, with an aluminium output of 125 000 $Mg.yr^{-1}$ (REAL et al., 2006a). Notification is on the Public Register at the EMA, of plans to double the capacity later by eastward extension of the pot lines.

Presently the Meteorological Services of Trinidad/Tobago collect comprehensive meteorological data at Piarco airport (island of Trinidad) and Crown Point airport (island of Tobago) only. The smelter applicants used the MM5 model to predict the wind pattern at the proposed smelter site at La Brea (island of Trinidad).

Fig. 3 shows the wind roses published in the proponent's Supplementary Environmental Impact Assessment (Figures 2.1 and 2.5, pages AVI-7 and AVI-9 in REAL et al, 2006b).

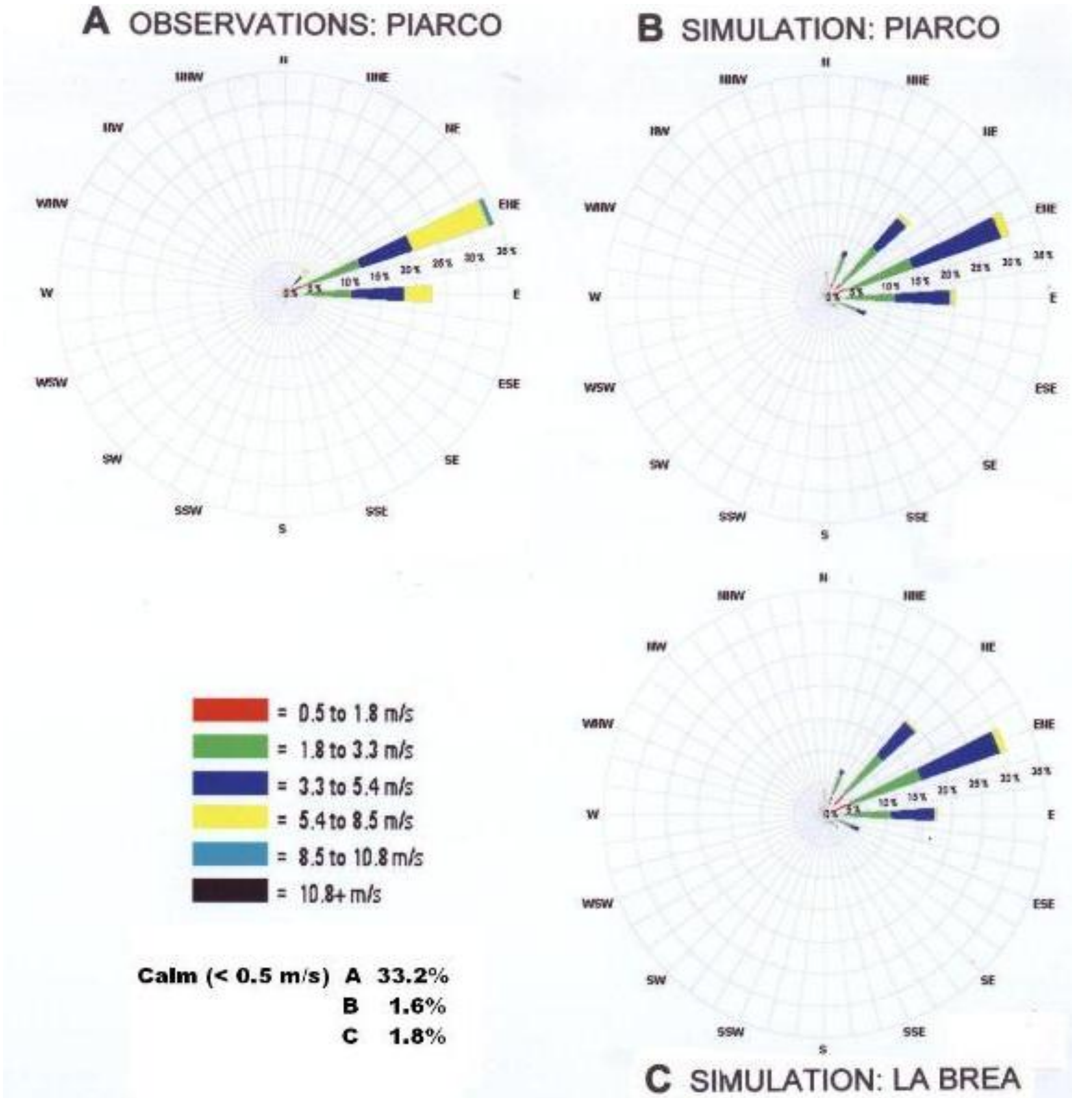

Fig. 3 Wind roses for year 2000 (REAL et al., 2006b): A, observations at Piarco airport; B, predicted at Piarco airport; C, predicted at La Brea smelter site.

2.1. PERFORMANCE OF MM5 METEOROLOGICAL MODEL AT PIARCO METEOROLOGICAL STATION

In Fig. 3, wind rose ‘A’ (winds observed, Piarco, year 2000) disagrees strongly with wind rose ‘B’ (winds predicted by MM5, Piarco, year 2000).

I have applied a Chi-square statistical test to compare the observed and predicted durations of different wind directions and speeds for Piarco. I read from the wind roses in Fig. 3, the duration of each combination of wind direction and speed (e.g. ENE at 3.3 to 5.4 $m.s^{-1}$) to the nearest 0.5%. As recommended by Everitt (1977) the Yates’s correction was used to calculate the Chi-square statistic and any duration which had expectation value (as defined by the Chi-square calculation of expectation) of less than 0.5%, was ignored.

The Chi-square statistic that describes the comparison between the observed and predicted wind direction and speed durations for Piarco was calculated as 49.21. This is greater than the Chi-square value of 38.58 given in standard statistical tables for 99.5% probability with the appropriate statistical degrees of freedom which is 19 degrees of freedom in the case of two paired sets of 20 durations each (these being the durations which had expectation value 0.5% or greater). Therefore there is a statistical probability greater than 99.5% that the predicted wind directions and speeds for Piarco do not arise from the same distribution as the observed wind directions and speeds. Accordingly I infer that there was poor MM5 model performance at Piarco and that wind directions and speeds predicted using MM5 at La Brea were therefore unreliable.

Of particular interest is the MM5 prediction of the percentage of time that the wind was calm (<0.5 $m.s^{-1}$). The observed percentage of time that the wind was calm at Piarco for the year 2000 was 33.2% (Fig. 3). This value is representative of the area over several years as evidenced by the wind rose for 1995-2004 for Piarco (Fig. 4) published by REAL (2007, Fig. 5-1, page 5-3) which shows that in the period 1995-2004 the observed duration of calm periods was 32.5%. However using the MM5 model, the predicted duration of calm periods at Piarco in 2000 was 1.6% (Fig. 3).

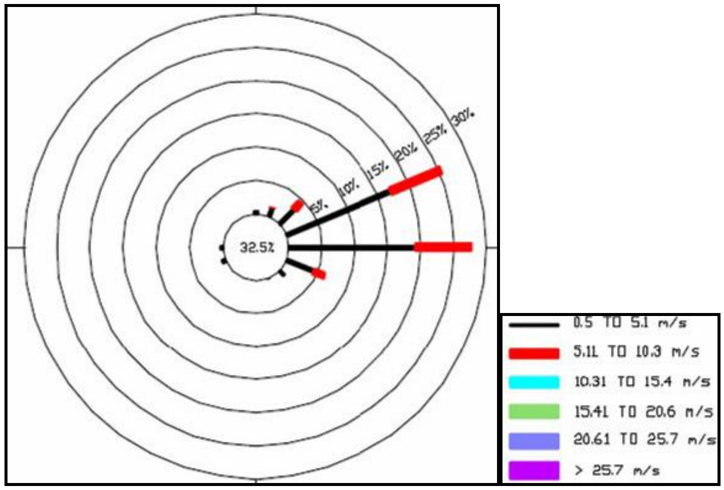

Fig. 4 Wind rose of observations at Piarco airport, 1995-2004 (REAL, 2007).

Thus the total duration of calm periods was grossly underestimated at Piarco by the MM5 model. The total duration of observed calms (33.2%) was more than 20 times the total duration of predicted calms (1.6%). Calm periods are the most unsafe for human and ecological life in close proximity to the proposed aluminium smelter complex, as airborne pollutants are not blown away during calms. Such a lack of wind to disperse airborne pollutants is doubly dangerous when there is also a temperature inversion, which causes emission plumes to remain near ground level instead of rising. Temperature inversions are common around dusk and dawn.

2.2. PERFORMANCE OF MM5 METEOROLOGICAL MODEL AT LA BREA COMPARED WITH PIARCO

In Fig. 3, wind rose ‘B’ (Piarco, predicted by MM5, year 2000) is virtually identical to wind rose ‘C’ (La Brea, predicted by MM5, year 2000). The MM5 model thus gives the unlikely conclusion that the wind pattern at Piarco is virtually the same as at the proposed La Brea aluminium smelter complex.

The magnitude of the actual differences in observed wind patterns when comparing Piarco and La Brea, is described in the text of the proponent’s Environmental Impact Assessment (EIA) (REAL et al., 2006a, Volume 1, page 5-6) based on data of unclear origin available to REAL et al.:

‘During the dry season, the prevailing wind occurred from an easterly direction 36% of the time at Piarco, and 89% of the time at La Brea. In the wet season, the prevailing wind from the easterly direction occurred 20% of the time at Piarco and 86% at La Brea.’

The wind pattern at Piarco is not likely to be the same as at La Brea because the two places are separated by 50 km of land mass; Piarco is inland whereas La Brea is on the sea coast; and Piarco is in a flat unforested plain whereas La Brea is in an area of forested rolling topography.

I calculated the Chi-square statistic for the comparison between the predicted pattern at Piarco and the predicted pattern at La Brea as 4.97. This is less than the standard Chi-square value of 7.43 at 0.5% probability on the appropriate 20 degrees of freedom. This means that there is a probability of less than 0.5% (less than 1 in 200) that the wind rose obtained by simulation for Piarco represented a different weather pattern than the wind rose obtained by simulation for La Brea.

Thus the wind data used to predict pollutant dispersion at the proposed smelter site are apparently erroneous in at least two separate ways. Firstly, a model was used which was erroneous when tested at Piarco. Secondly, the model predicted that La Brea would experience wind conditions almost identical to those at Piarco, which appears incredible.

The MM5 prediction that calms occupy 1.8% of the time (i.e. on average 26 minutes per day) at the smelter site (Fig. 3), is a gross underestimate compared with numerous personal experiences by myself throughout 2006, 2007, and 2008 at the site (which was bulldozed clear of vegetation in 2004) and within neighbouring settlements. This was confirmed by interviews with residents and would be resolved if there were a meteorological station at the site.

2.3 PREDICTED POLLUTANT CONCENTRATIONS AT OUTER EDGE OF BUFFER ZONE

A vegetated buffer zone of 100 m width was designated around the plant boundary. In the project design for which a CEC was awarded, the ADM (CALPUFF, using MM5 meteorological data) predicted that the highest 24-h average airborne hydrogen fluoride (HF) concentration occurring at ground level once per year at the outer edge of the buffer zone would be 0.83 $\mu g.m^{-3}$ (REAL et al., 2006c, p. 10). This HF concentration is to be compared with the EMA's 24-h average stipulation of a maximum of 1 $\mu g.m^{-3}$.

In the prediction process there was no conservatism that could tend to cause overestimation of concentrations.

The unreliable wind data described in Sections 2.1 and 2.2 above, tend to negate the smelter pollution predictions. In particular, evidence was given above that the calm periods (potentially the most dangerous periods) were grossly underestimated. The unreliability is particularly serious in view of the fact that the predicted concentrations of airborne pollutants are virtually at the maximum limits allowed by the EMA.

Compounding the unreliability of the wind data are (1) the general uncertainty arising in the use of ADMs, including CALPUFF, for predicting concentrations of airborne emissions; (2) the variability that inevitably exists around the engineering design values for the amounts of emissions from each emission source; and (3) the possible additive effects of different pollutants on the same human receptor.

3. IRON AND STEEL PLANT

Essar Limited proposes to convert iron ore fines to iron ore pellets and hot briquetted iron, and after a year or two to begin producing direct reduced iron (DRI) and 2.7 x 10^6 $Mg.yr^{-1}$ of hot rolled steel coils (SENES Consultants Ltd and EPAS Consultants Ltd, 2006). As with the aluminium smelter complex (above), the Public Register at the EMA also records plans to double the capacity later, by eastward extension.

Fig. 5 shows the wind rose published in the proponent's EIA (SENES Consultants Ltd and EPAS Consultants Ltd, 2006). The proponents used the Piarco weather observations for modelling air dispersion.

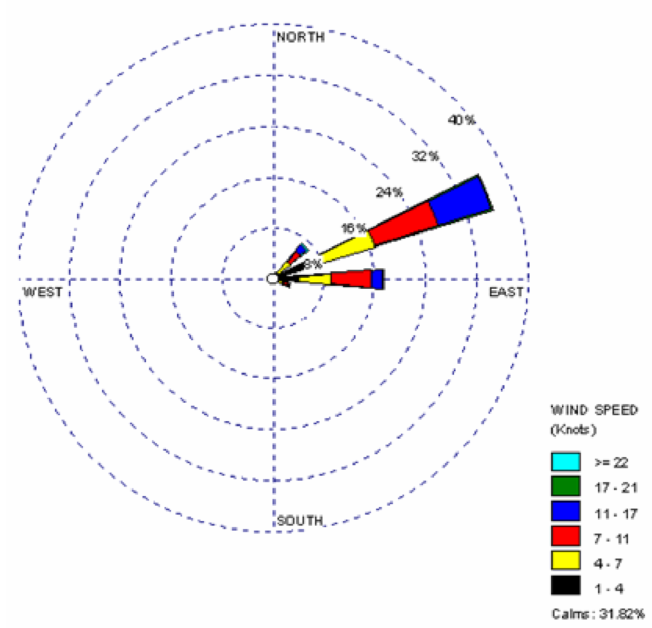

Fig. 5 Wind rose of observations at Piarco airport, 2004 (SENES Consultants Ltd and EPAS Consultants Ltd., 2006).

The ADM used was ISC3. Fig. 6a shows the published prediction of 24-h SO_2 concentrations. In Fig. 6b, the diagram of Fig. 6a has been shaded by an independent graphic artist for the purpose of clarity, darker shading corresponding to higher SO_2 concentration.

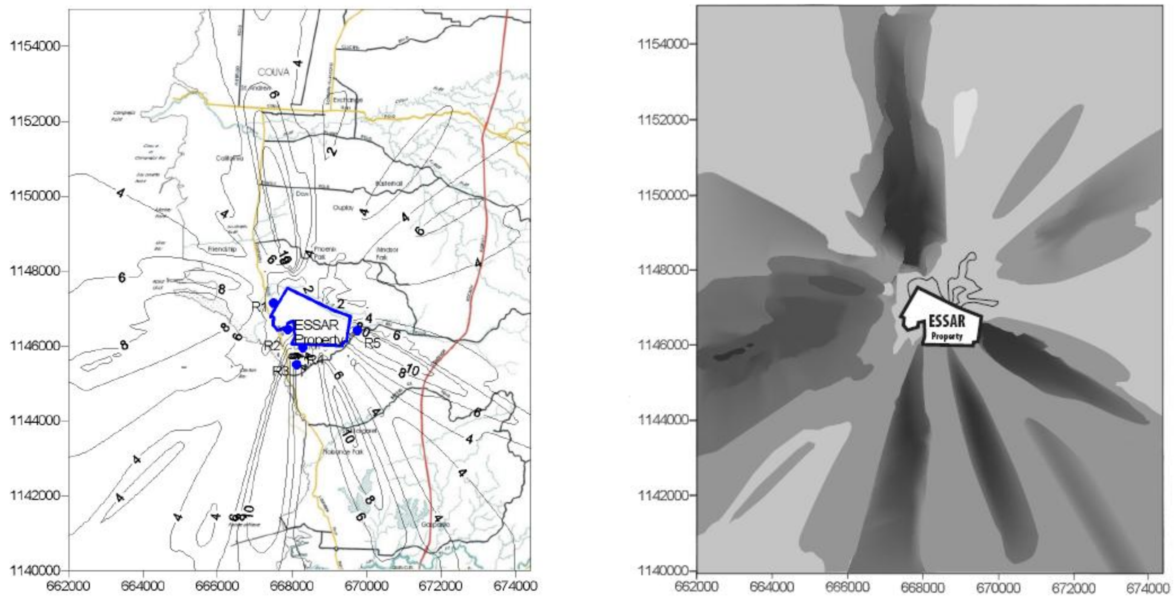

Fig. 6 Predicted annual maximum 24-h-mean SO_2 concentration ($\mu g.m^{-3}$) around proposed steel mill: Map 6a (first map) as published in EIA (SENES Consultants Ltd and EPAS Consultants Ltd., 2006); Map 6b (second map) as shaded by independent graphic artist (darker shade denotes higher concentration).

A bicycle-spokes pattern is evident in the Figures for the proposed steel mill.

It is not known what caused the bicycle-spokes pattern of predicted pollutant concentration. The bicycle spokes appear to be at regular intervals of 22 ½ ^{o}, the same interval as occurs between spokes in the wind rose. It may be that the ADM model produced a spoke of high pollutant concentration for each spoke of the wind rose. Of course, a spoke in the wind rose, e.g. the North North East (NNE) spoke, does not refer to wind coming from an exact bearing equal to some multiple of 22 ½ ^{o}, but instead refers to all wind from the sector, e.g. 11 ¼ ^{o} to 33 ¾ ^{o}, centred at 22 ½ ^{o}. Thus the pollution would not be concentrated as in a bicycle spoke at exactly 22 ½ ^{o}.

Extensive field observation by this author, confirmed by the topographic contours, roads, and built-up areas seen by close examination of Fig. 6a, reveal that, in and around the area represented in the map, there are no topographic, land use, or other features that correspond to the bicycle-spoke air dispersion pattern.

A more justifiable dispersion pattern is the one in Fig. 7, produced for 24-h SO_2 for the ISPAT-SIDEX steel plant in Romania (Balanescu et al., 2004). The roughly concentric iso-concentration lines in this pattern indicate that the spread of pollution would not be predominantly in specific narrowly-defined directions.

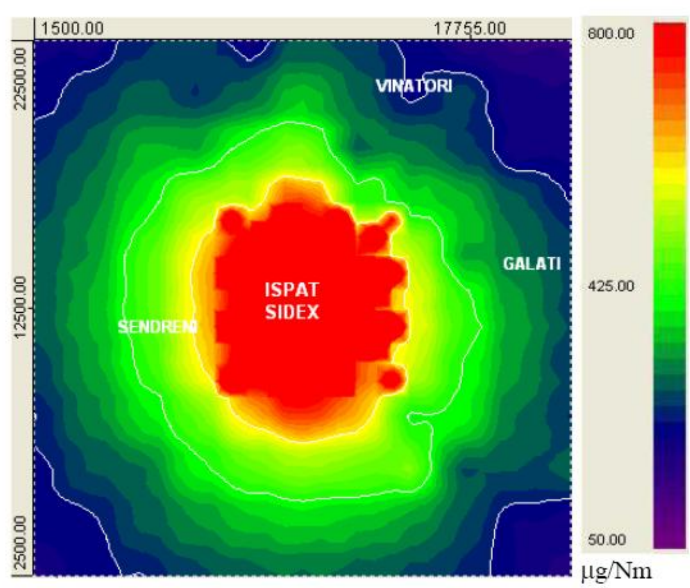

Fig. 7 Predicted maximum 24-h-mean SO_2 concentration ($\mu g.m^{-3}$) around a steel mill in Romania (Balanescu et al., 2004). Names on map indicate villages.

It does not appear possible to find any physical justification for a bicycle-spoke pattern of high pollutant concentrations at the proposed Trinidad/Tobago plant. It does not appear possible even to apply any interpretation of the bicycle-spoke output to deduce realistic concentrations.

I conclude that the ADM output published in the EIA is erroneous, although the output was apparently accepted by the EMA for the CEC which was awarded. More realistic in practice is the emission seen emanating daily from a standard Direct Reduced Iron (DRI) plant moved from the U.S.A. and restarted in 2006 on the coast of Trinidad (CacheValley Electric, 2006), 4 km from the proposed Essar site (Fig. 8). A standard DRI plant is only one part of the integrated iron and steel plant proposed by Essar. The Essar plant is proposed to be immediately upwind of pre-existing residential areas.

Fig. 8 Typical visible emissions from Direct Reduced Iron (DRI) plant of NuIron Corp. in Trinidad/Tobago, 2008. Photo by Ryan Sant.

The ISC3 model is no longer a preferred regulatory model in the USA (USEPA, 2005).

4. CHLOR-ALKALI PLANT

The proposed chlor-alkali plant of Carisal Ltd would be located next to the proposed iron and steel plant of Essar Ltd. According to an updated proposal by Carisal (Carisal Unlimited, 2008) the plant would have nominal production capacity of 100 000 $Mg.yr^{-1}$ of NaOH, 125 000 $Mg.yr^{-1}$ of $CaCl_2$, 53 000 $Mg.yr^{-1}$ of NaOCl, 85 000 $Mg.yr^{-1}$ of HCl, plus the release of 170 000 $Mg.yr^{-1}$ of CO_2 less 50 000 $Mg.yr^{-1}$ of CO_2 which might go to an independent urea plant. Input is stated to include brine and limestone.

Fig. 9 shows some of the ADM output published in the EIA (Da Costa Gwendoline Ltd. and ICF International, 2008). The ADM model used was AERMOD. AERMOD is designed to be the successor to ISC3 (Federal Register, 2000). Again the apparently erroneous bicycle-spoke pattern has been produced.

5. CONCLUSION

It is concluded that the published ADM outputs for the proposed plants are erroneous, and that therefore the CECs must be withdrawn for the aluminium smelter complex and for the steel plant, and the pending CEC application for the chlor-alkali plant must be put on hold.

6. ACKNOWLEDGEMENTS

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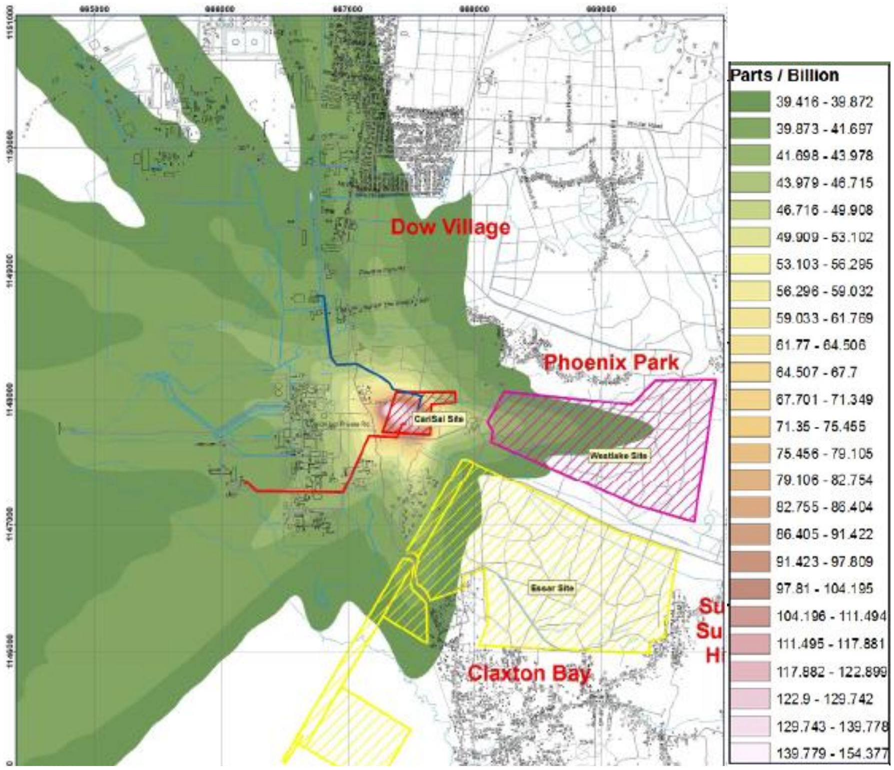

Fig. 9 Predicted annual maximum 1-hour-mean NO_2 concentration arising from the proposed chlor-alkali plant during construction phase, not including background NO_2 (Da Costa Gwendoline Ltd. and ICF International, 2008, Appendix E Data and Unpublished Documents, Fig. 32).

7. REFERENCES

Balanescu M, Hritac M, Melinte I, Nicolae A. Environmental impact assessment of an industrial accident using ISC-AERMOD View. A case study. 9th Int. Conf. on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Garmisch-Partenkirchen, Germany, 1-4 June 2004, 346-350. http://hamo.org/Conferences/Proceedings/_Garmisch/publishedSections/7.03.pdf

Boucouvala D, Bornstein R, Miller D, Wilkinson J. MM5 simulation of the meteorological conditions during a South coast ozone study (SCOS’97) episode. In: Gryning SE, Schiermeier FA, editors. Air Pollution Modeling and Its Application XIV, Plenum Publishers; 2001, 683-690.

Builtjes PJH. Major twentieth century milestones in air pollution modeling and its application. In: Gryning SE, Schiermeier FA, editors. Air Pollution Modeling and Its Application XIV, Plenum Publishers; 2001, 3-16.

Cache Valley Electric. Nu-Iron Unlimited—Trinidad. Cache Valley Electric Newsletter, www.cve.com; 2006, 7(3): 1

Carisal Unlimited. Letter of 31 July 2008 from Carisal Unlimited to EMA. On Public Register for CEC application CEC1743/2006 at EMA, Trinidad & Tobago.

Da Costa Gwendoline Ltd., ICF International.. Environmental Impact Assessment for a Proposed Chlor-alkali Plant and Associated Infrastructure at Point Lisas, Trinidad and Tobago. On Public Register for CEC application CEC1743/2006 at EMA, Trinidad & Tobago; 2008.

Everitt BS. The Analysis of Contingency Tables. Chapman & Hall; 1977.

Federal Register. Requirements for Preparation, Adoption, and Submittal of State Implementation Plans (Guideline on Air Quality Models); Proposed Rule. Federal Register (US), 21 April 2000 (Vol. 65, No. 78). http://gpoaccess.gov/fr/

Kretzschmar JG. Why and how to harmonise air pollution impact assessment models? In: Gryning SE, Schiermeier FA, editors. Air Pollution Modeling and Its Application XIV. Plenum Publishers; 2001, 17-24.

Protonotariou A, Bossioli E, Athanasopoulou E, Dandou A, Tombrou M, Flocas HA, Helmis CG, Assimakopoulos VD. Evaluation of CALPUFF modelling system performance: an application over the Greater Athens Area, Greece. 9th Int.

Conf. on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Garmisch-Partenkirchen, Germany, 1-4 June 2004. http://harmo.org/Conferences/Proceedings/_Garmisch/publishedSections/PPT/1.27-Protonotariou.pdf

REAL (Rapid Environmental Assessments (2003) Ltd), Komex Europe Ltd, Foster Solutions, SENES Consultants Ltd, Earth Tech. 2006a. Environmental Impact Assessment for a Proposed Aluminium Smelter Complex to be Sited at Main Site North, Union Industrial Estate, La Brea. January 2006. On Public Register for CEC application CEC1033/2005 at EMA, Trinidad & Tobago.

REAL, Komex Europe Ltd, TRC Solutions Ltd. 2006b. Environmental Impact Assessment Study for the Establishment of an Aluminium Complex at Main Site North, Union Industrial Estate, La Brea, Trinidad. Supplementary Report. August 2006. On Public Register for CEC application CEC1033/2005 at EMA, Trinidad & Tobago.

REAL, CMEC (China National Machinery & Equipment Import & Export Corporation), NEUI (North Eastern University Engineering & Research Institute), TRC Solutions Ltd, Alutrint Ltd. 2006c. Environmental Impact Assessment Study for the Establishment of an Aluminium Complex at Main Site North, Union Industrial Estate, La Brea, Trinidad. Addendum to Supplementary Report. November 2006. On Public Register for CEC application CEC1033/2005 at EMA, Trinidad & Tobago.

REAL. Environmental Impact Assessment for a Proposed 24-inch Natural Gas Distribution Pipeline from Point Fortin to the Union and La Brea Industrial Estates, La Brea. On Public Register for CEC application CEC1678/2006 at EMA, Trinidad & Tobago; 2007.

SENES Consultants Ltd., EPAS Consultants Ltd. Environmental Impact Assessment Study for Proposed Steel Complex at Point Lisas, Trinidad & Tobago. On Public Register for CEC application CEC1248/2005 at EMA, Trinidad & Tobago; 2006

USEPA (United States Environmental Protection Agency). Revision to the Guideline on Air Quality Models. Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule. 40 Federal Register; 2005; 70; 68218.

Venkatram-A. Challenges of air pollution modelling and its applications in the next millennium. In: Gryning SE, Schiermeier FA, editors. Air Pollution Modelling and Its Application XIV, Plenum Publishers; 2001, 613-630.