



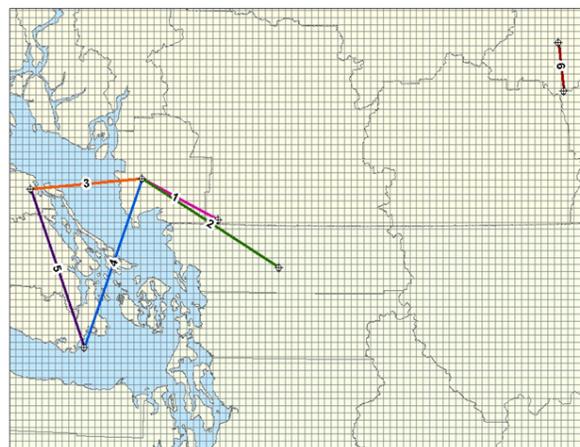
Lines of Sight Study over Pacific Northwest Using CMAQ

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1. INTRODUCTION

- Visibility degradation, or 'haziness' is strongly influenced by changes in emissions, ambient meteorology and atmospheric chemistry. A quantitative measure of visibility impairment, expressed as DeciView (Dv), is a useful parameter that can help to assess air quality within a region.
- Since 2003, the authors have been involved in study to set up, test, and deliver to Environment Canada a unique air quality modelling system comprised of the following components: the MC2 meteorological model, the SMOKE emission data processing system, and the CMAQ photochemistry/transport model.
- Initial work focused on preparation of a comprehensive air quality modelling to satisfy unique research and application needs of Environment Canada in the Pacific Northwest, which included capability to evaluate impacts of Canadian and U.S. emissions from anthropogenic and natural sources on: ozone, fine particulate matter, visibility and deposition. Over the past three years the project involved:
 - Preparation of MC2 meteorological data on specific projections and domains
 - Compilation and processing of emission inventory data through SMOKE for over 25 emissions scenarios, and
 - Model performance for typical Summer and Winter periods
- To assist in analysis of how visibility is affected by different emissions, six Line of Sight were defined within the 4km innermost PNW CMAQ domain. Visibility impairment, or haziness, expressed as Dv, was calculated from CMAQ model results along each of these lines.
- The study revealed that haziness along Lines of Sight responded not only to emission changes but also to other factors, most notably ambient meteorology. For example, large reduction of NO_x from marine emissions had only a small impact on visibility due to presence of fog in marine areas.

Line of Sight (LOS) transects and 4 km CMAQ Grid



LOS Reference	Latitude (DD.DDDD)	Longitude (DDD.DDDD)	Reference	Latitude (DD.DDDD)	Longitude (DDD.DDDD)
1	GVRD Bldg, 4330 Kingsway, Burnaby	49.2309N 123.0076W	Abbotsford	49.0234N	122.3438W
2	GVRD Bldg, 4330 Kingsway, Burnaby	49.2309N 123.0076W	Mt. Baker	48.777N	121.811W
3	GVRD Bldg, 4330 Kingsway, Burnaby	49.2309N 123.0076W	Nanaimo, Melaspina College	49.1590N	123.9670W
4	GVRD Bldg, 4330 Kingsway, Burnaby	49.2309N 123.0076W	Victoria, Royal Roads 2005 Spoke Road	48.3333N	123.4684W
5	Victoria, Royal Roads 2005 Spoke Road	48.3333N 123.4684W	Nanaimo, Melaspina College	49.1590N	123.9670W
6	Kelowna Airport	49.9553N 119.3730W	Little White Mountain	49.7000N	119.3333W

2. EMISSIONS SCENARIOS

- **Agricultural Emissions Change Scenarios**
20%, 40%, 60% and 80% reductions in Agricultural NH₃
- **Transboundary Flow Scenarios**
All US anthropogenics turned off
All Canadian anthropogenics turned off
- **Air Quality Management Plan (AQMP)**
2015 Base Case
2015 Additional AQMP Actions
2015 Marine Emissions Reduction
2015 Non-Road Emissions Reduction
2015 Point Sources Emissions Reduction
2015 AQMP Actions Plus – (all of the above)

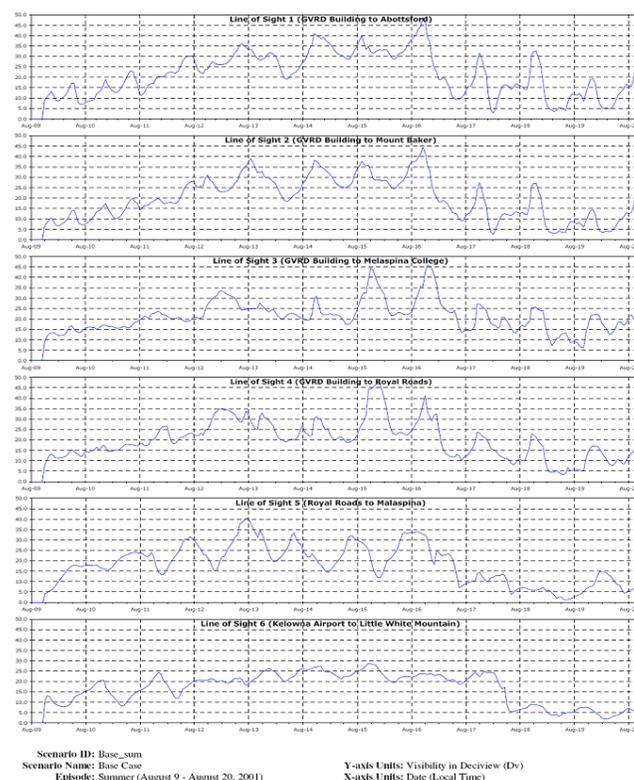
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3. AIR QUALITY AND VISIBILITY MODELLING METHODOLOGY

- Visibility index developed by Pitchford and Malm (1994) has been adopted in CMAQ. Scale of this visibility index, expressed in DeciView (Dv), is linear with respect to perceived visual changes over its entire range, and is analogous to decibel scale used in acoustics.
- Given by:
$$Dv = 10 \ln \left[\frac{b_{ext}}{10} \right] \quad (1)$$
 where b_{ext} is the light extinction coefficient relative to background light extinction
- For calculation of (1) b_{ext} is extracted from CMAQ model results along the chosen Line of Sight. Represents sum of extinction from all modeled species
- Six Lines of Sight chosen to Reflect different influences along different areas: Lines 1,2 represent Greater Vancouver inland urban/suburban areas, Lines 3,4 show marine, Line 5 represents Greater Victoria and suburbs, Line 6 shows a smaller inland valley (Kelowna) location
- Results presented in form of time series of Dv integrated along each line at each hour
- Detailed description of calculation of DeciView can be found in Models-3 manual (Benjey, 1999)

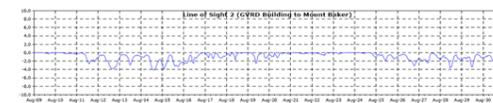
4. BASE CASE RESULTS AUGUST 2001

- Lines of Sight for Summer 2001 Base Case indicate general temporal pattern of visibility from all six lines consistent with trends in PM_{2.5}
- Deciview (Dv) values gradually increase from August 9 to 16 and then decrease sharply afterward
- Lines of Sight 1 and 2 extending from Vancouver southeast show diurnal cycle with peaks in the morning or late afternoon during stagnant phase (August 9 to 16), likely due to impact of sea-land breeze and mountain-valley flow patterns. Dv values gradually increase (going from 13 to 47) until August 16. After August 16, pattern for these two Lines of Sight changes and becomes more irregular due to synoptic weather changes
- Lines 3 and 4 across Strait of Georgia from Vancouver to Vancouver Island and Line 5 on southern part of the island exhibit more irregular behavior through beginning of the model period (August 9 to 11), but develops diurnal cycle and reaches a peak between August 12 and August 16 (up to 47 Dv along Line 4)
- Lines 3, 4 and 5 generally depict the influence of marine emission
- Line 6 through the Okanagan Valley shows lower Dv values consistent with location in region of smaller population and lower emissions.

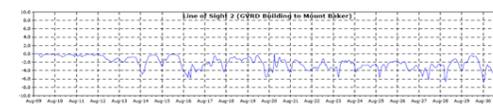


5. VISIBILITY CHANGES IN RESPONSE TO EMISSIONS SCENARIOS

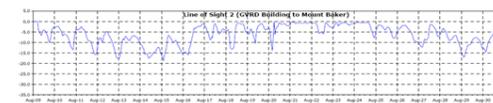
Line of Sight 2 – Greater Vancouver to Mount Baker



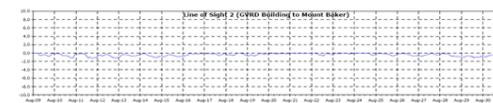
80% Reduction Agricultural NH3 Emissions



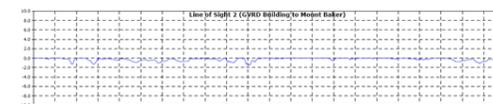
US Anthropogenic Emissions Removed – 4km Domain



Canadian Anthropogenic Emissions Removed – 4km Domain



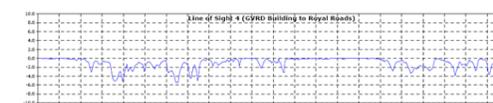
AQMP Actions*



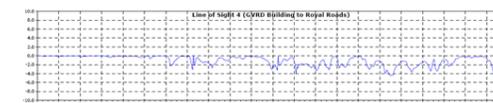
Marine Emissions Reduction Strategies*

- Agricultural emissions have noticeable impact on both over-land and over-water visibility
- Anthropogenic emissions from Canada are largest contributors to visibility degradation
- US anthropogenic emissions about 1/3 of effect on visibility as Canadian based anthropogenic emissions
- Marine emission reduction has stronger effect over ocean (Line of Sight 4), but effect on overall visibility is less than anticipated
- AQMP actions have up to 1.8 Dv on visibility improvement

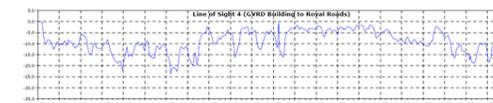
Line of Sight 4 – Greater Vancouver to Victoria



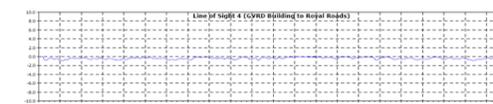
80% Reduction Agricultural NH3 Emissions



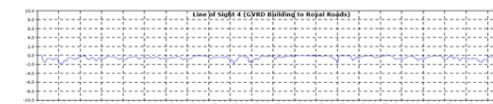
US Anthropogenic Emissions Removed – 4km Domain



Canadian Anthropogenic Emissions Removed – 4km Domain



AQMP Actions*

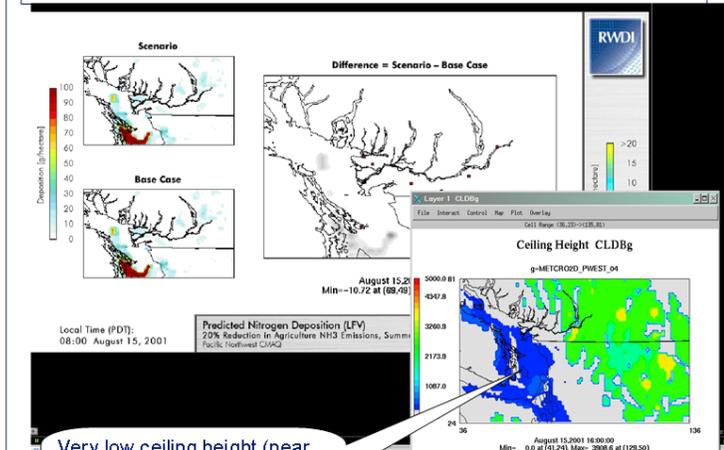


Marine Emissions Reduction Strategies*

* With respect to 2015 Base Case

5. METEOROLOGICAL INFLUENCES AND UNCERTAINTIES

- Meteorological conditions can be a large factor in influence of various emissions strategies on predicted visibility.
- For example, the Base Case shows high Dv values on August 16 for Line of Sight 4. While looking into detail of meteorological conditions, we found that although no precipitation predicted from MC2 modeling, low-level cloud and fogs contributed significantly to the secondary particulate, which in turn contribute to
 - increase in wet deposition
 - decrease in visibility
- This example indicates that predicted meteorological parameters may cause uncertainties on the air quality prediction levels and users modellers need to be aware of such occurrences within the model.



6. CONCLUSIONS

- Visibility impairment, expressed as Dv, extracted from CMAQ model provides useful measure of quantitatively assessing visibility or haziness within the PNW model domain
- Lines of Sight for Agricultural scenarios indicate a general improvement with increasing reductions (20% to 80%). This is mainly due to the reduction in secondary aerosol levels (ammonia PM).
- Canadian based anthropogenic emissions have a large impact on visibility in coastal areas and throughout the Lower Fraser Valley.
- Effect of US anthropogenic emissions peaks at about 8 Dv, or about 1/3 effect of Canadian emissions. US emissions have little effect on inland regions AQMP Action show minor improvement in visibility in coastal areas and the Lower Fraser Valley.
- Marine emissions reductions show minor improvement in visibility, though less than expected over marine areas.
- Local meteorological conditions can greatly affect model visibility results. Fog and atmospheric moisture in marine boundary layer may have masked expected visibility improvements in these areas.

7. REFERENCES

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6. ACKNOWLEDGEMENTS

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