A Retrospective Analysis of Ozone Formation in the Lower Fraser Valley, Canada.

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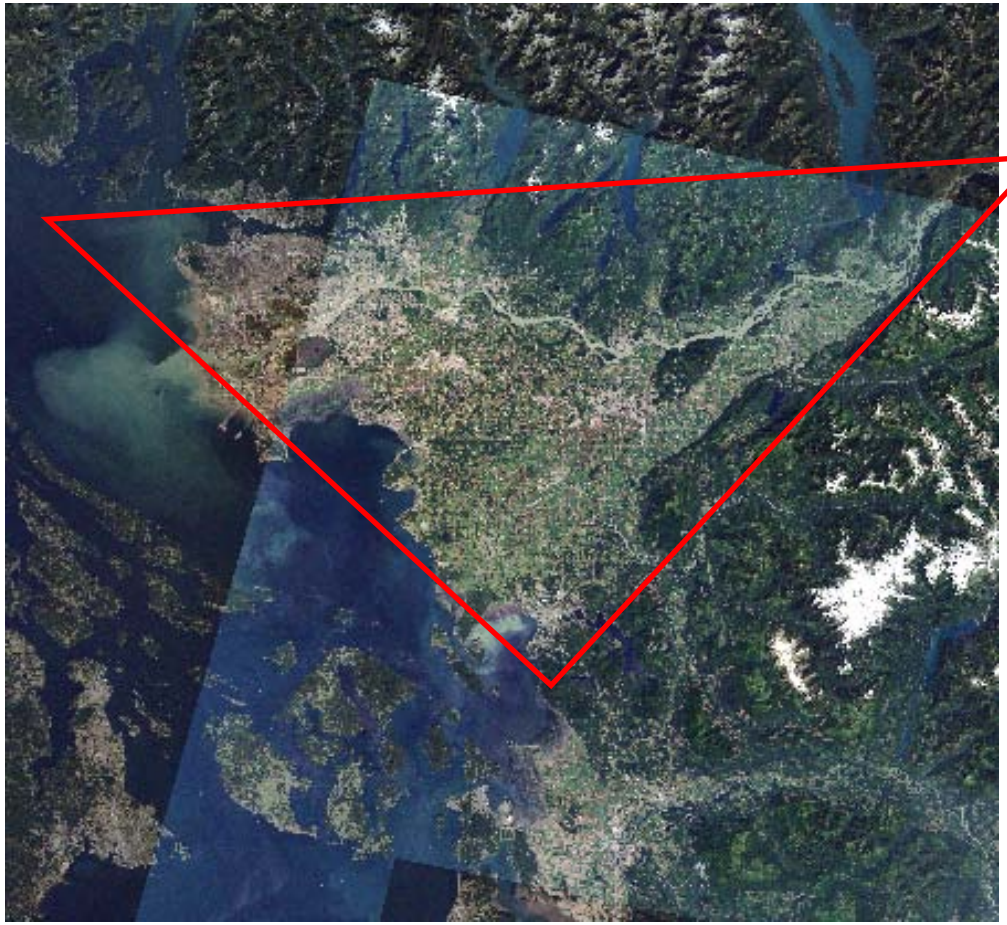
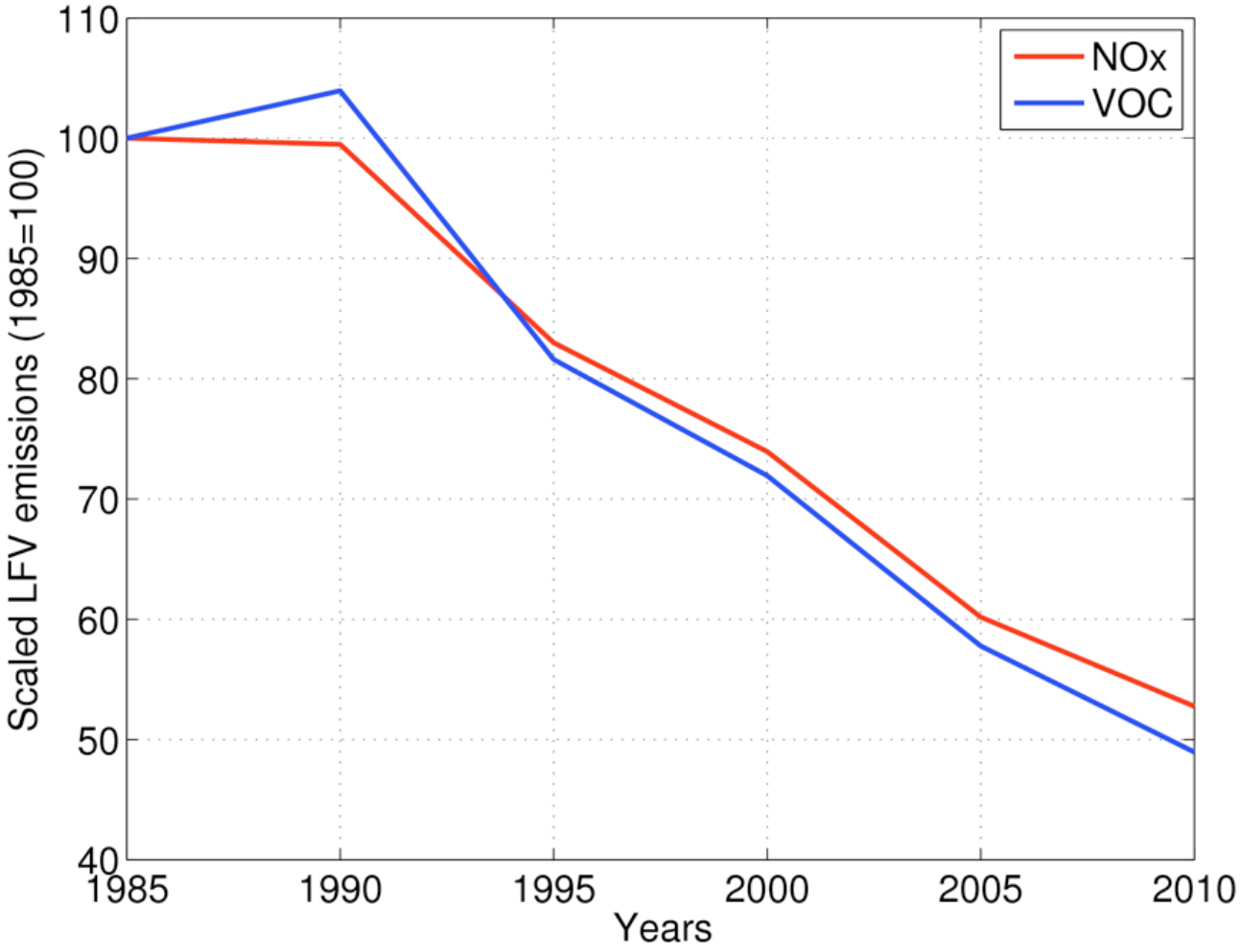
Background



- Triangular valley
- ~2 million people
- LFV undergone a sizeable valley-wide emission reductions.

LFV NOx and anthropogenic VOC Emission Totals



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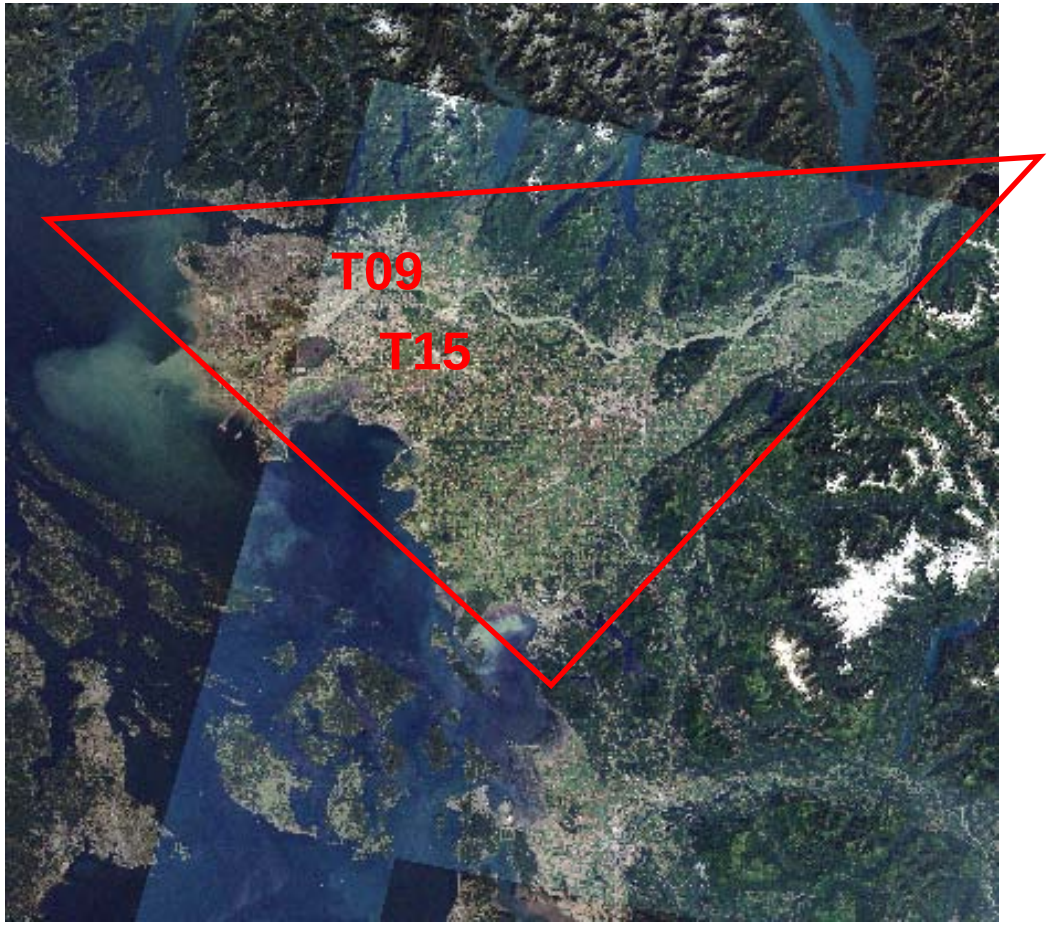
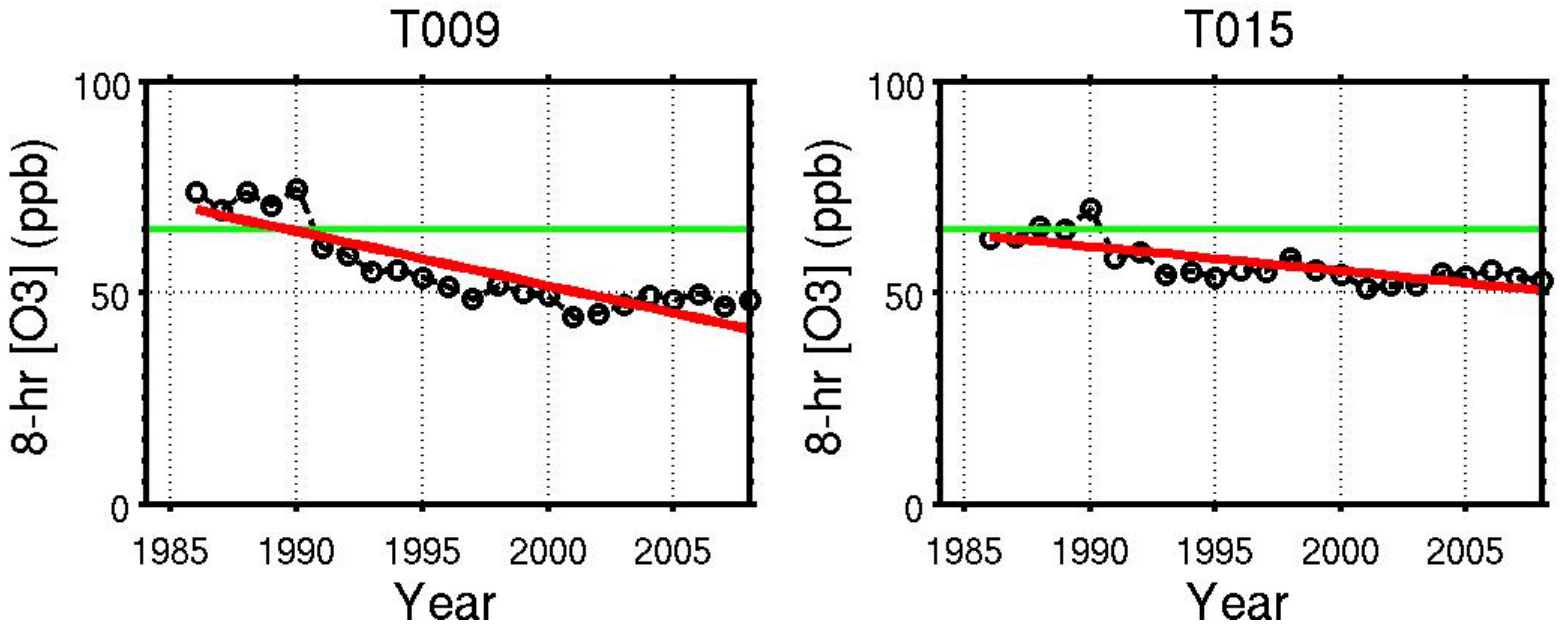


- The observed ambient ozone reductions have not been uniform across the valley
- Western LFV noticeable ozone reductions

CWS Trends at 2 western stations



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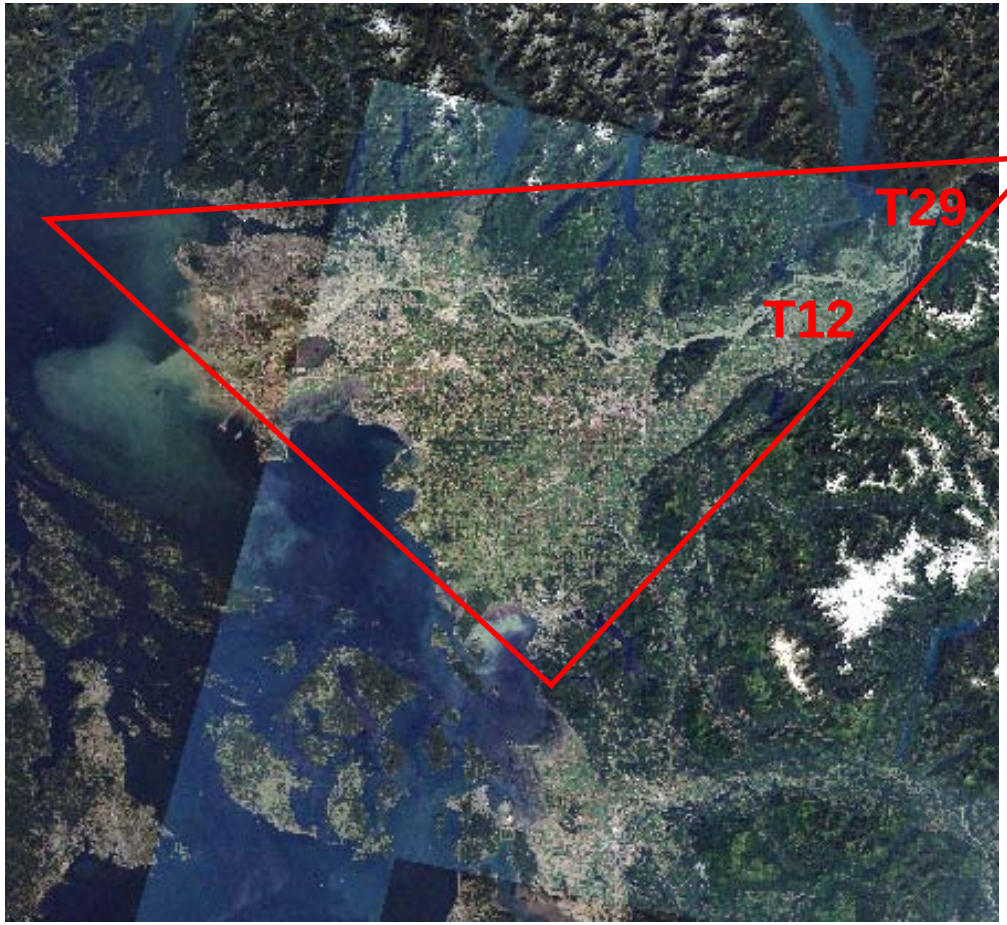
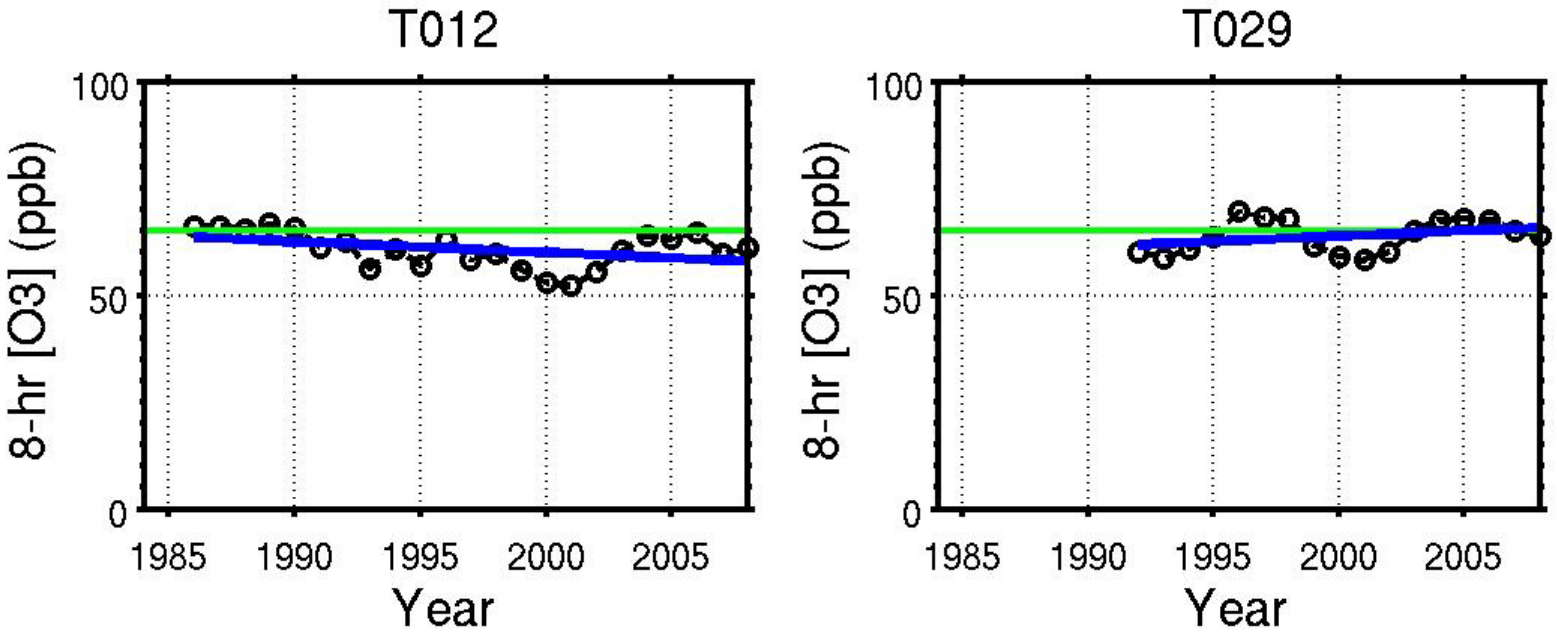


- Eastern LFV little or no improvement their maximum 8-hr averaged ozone concentrations

CWS Trends at 2 eastern stations



Research Questions

- What has caused the relative decline in ozone air quality in the upper part of the Lower Fraser Valley (Abbotsford to Hope) over the past two decades?
- What is the importance of changes in emissions (reactivities as well as amounts) relative to spatial shifts in emissions densities in governing the noted spatio-temporal changes in LFV air quality over the past two decades?

Research Design

Investigating these questions is simplified because:

1. There appears to be little or no impact from precursor emissions upwind of the LFV during ozone episodes;
2. background concentrations of ozone and its precursors are generally from the North Pacific and are quite low.

As a result:

→ ozone formation in the LFV is almost entirely due to local emissions

→ observed change in behaviour of ozone formation must arise from observed reductions in precursor emissions.

Unintended natural experiment

In essence, an **unintended natural experiment** has taken place and which we exploit in two ways:

- We use emission changes and the associated air quality changes to perform a dynamic model evaluation of the WRF-SMOKE-CMAQ modeling system.
- We run the model with fixed meteorology and emissions from 1985 and 2005 to explore the LFV ozone-precursor relationship.

Complications

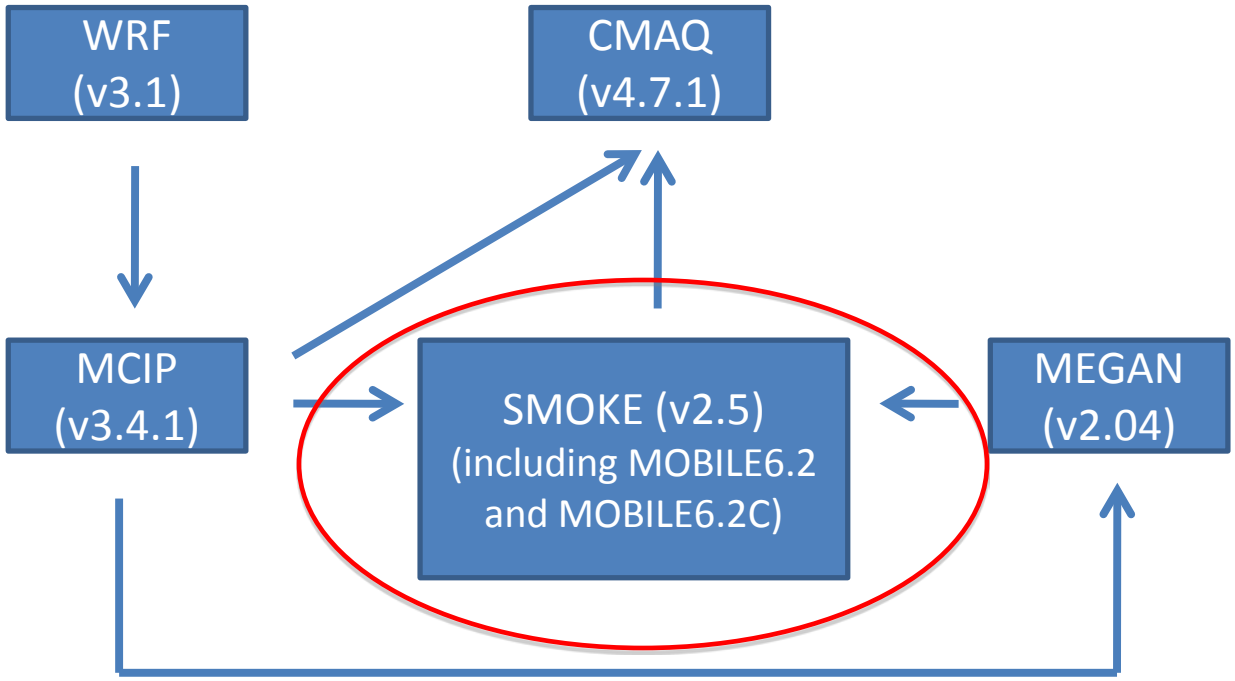
Associated with the observed emission changes are two potentially complicating factors:

- There has been an observed shift in the population patterns within the valley over the last 25 years
- There has been a small but documented change in the background concentration of ozone

Approach

Investigate using system of numerical models:

- Meteorology (WRF)
- Emissions (SMOKE+MEGAN)
- Chemical transformations (CMAQ)



Emissions Modeling

- Annual NOx, VOCs, CO emission totals from MV present and backcast inventories used to drive SMOKE
- Spatial surrogates dynamically adjusted based on changes in population density
- SMOKE set-up to produce inventories for: LDV&HDV (via MOBILE 6.2 and MOBILE 6.2C), off-road, railroads, aircraft, marine, other mobile sources, biogenic emissions, point, and area sources.
- Biogenic emissions modeled using MEGAN and held fixed over the 20 yr (1985-2005) analysis period

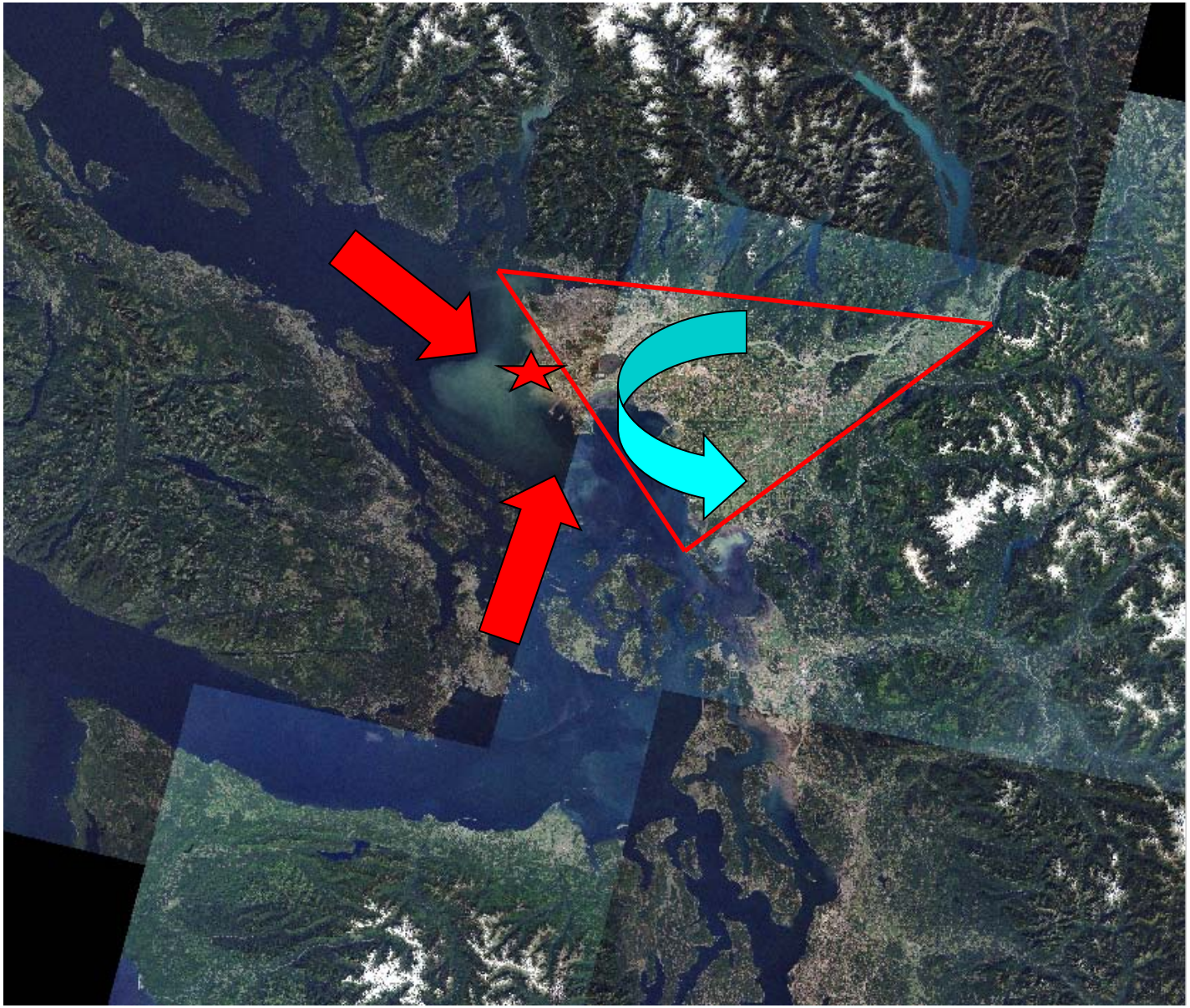
Meteorological Modeling

Exercising model over a range of ozone events.

Events chosen so that they:

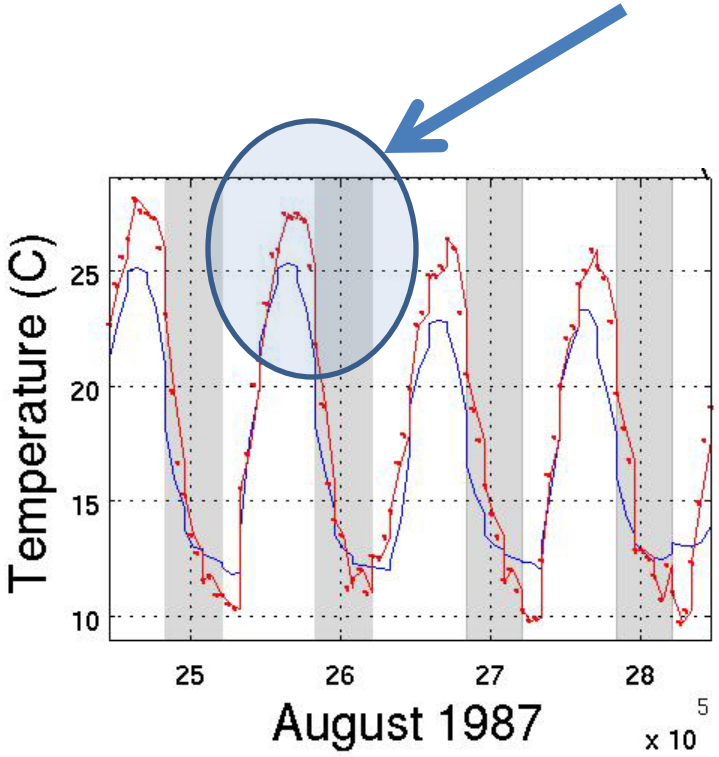
- They span period of greatest emission change
- Include all meteorology typical of ozone events
- Coincide as much as possible with previous research

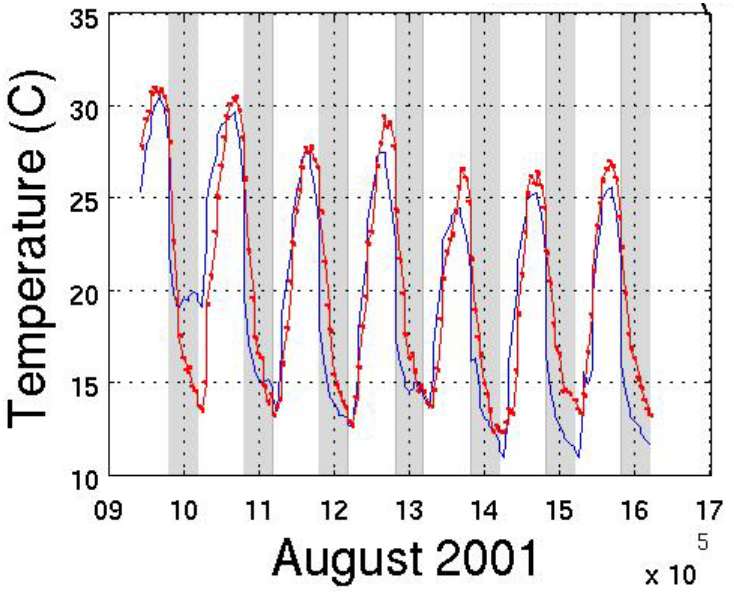
Ozone episode circulation regimes



Ainslie and Steyn (2007) identified 4 meso-scale circulation regions typically found during LFV ozone events

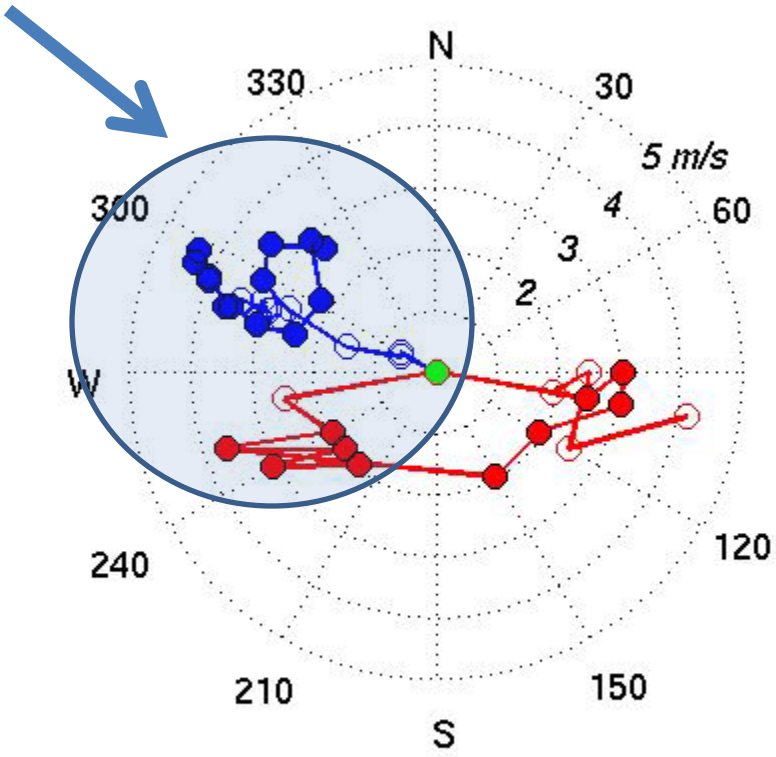
Results: Meteorological Modeling



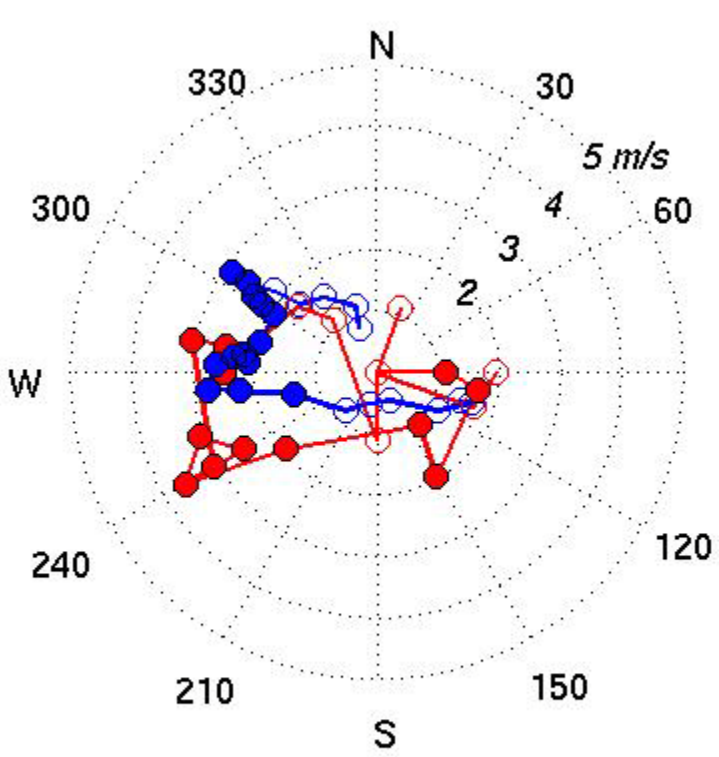


Inland (YXX) temperature timeseries

Results: Meteorological Modeling



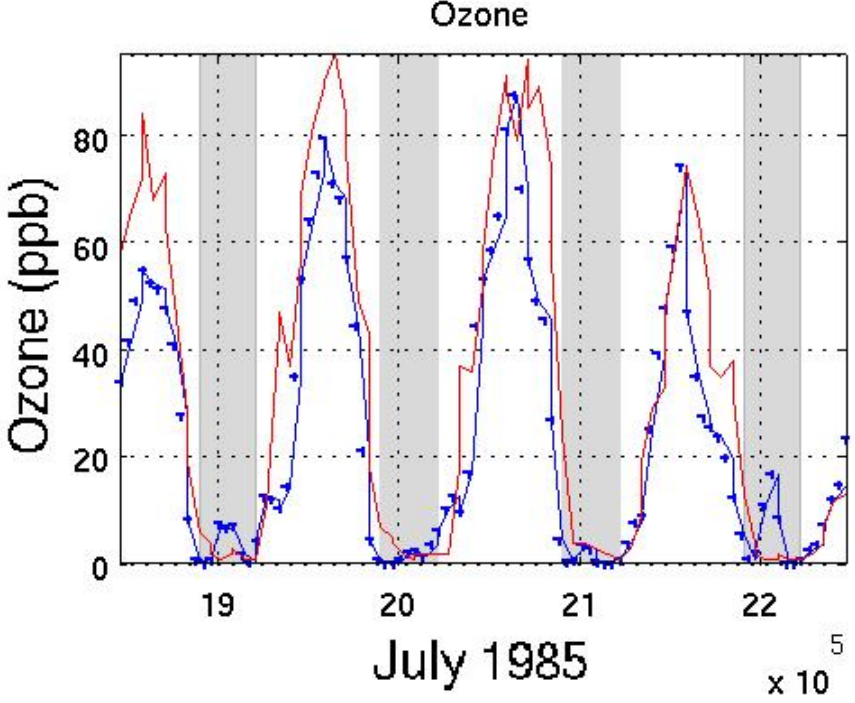
27-Aug-1987 (IV)



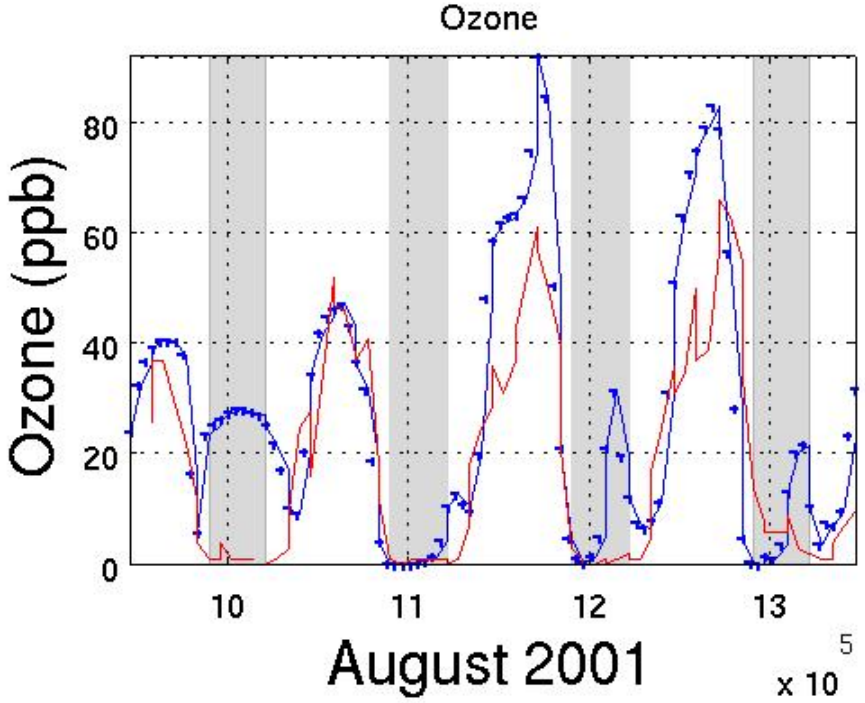
12-Aug-2001 (II)

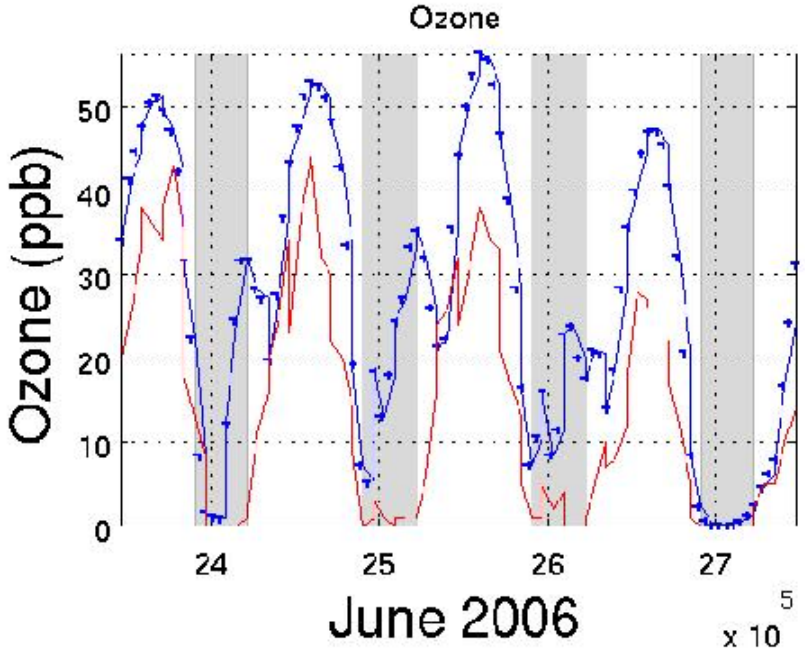
Coastal (YVR) hodographs

Results: Ozone Modelling

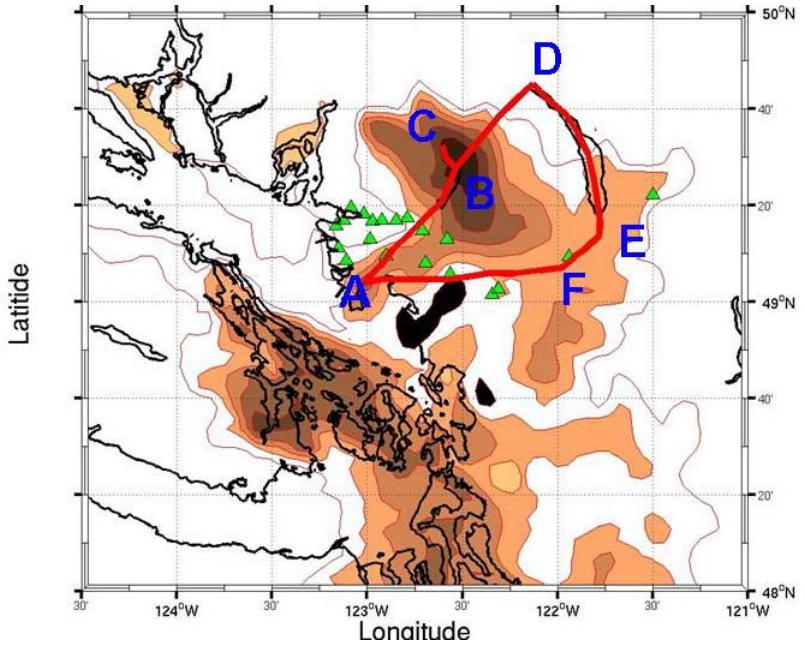


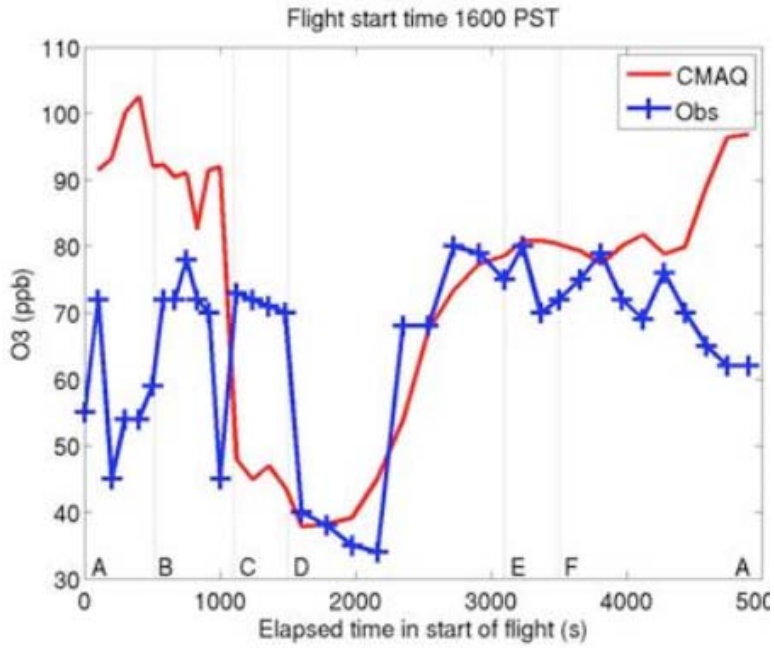
T09 observed (red) modeled (blue) ozone. Good agreement (1985), okay (2001), poor (2006)





Model evaluation





- Further evaluation using: Temperature, NOx fields, VOC spot measurements, previous modeling exercises and field campaign data
- Modelled ozone compared with aircraft observed ozone in 1995 field study (McKendry et al. 1998)

Model evaluation summary

Since:

→ the purpose of the validated modelling system is to analyse mechanisms linking spatio-temporal shifts in LFV emissions to observed spatio-temporal shifts in LFV ozone plume.

Given:

→ When exercised over a range of episodes, the model is responsive to the changes in emissions between 1985 and 2005.

→Magnitude of the response is comparable to observed changes in the LFV ozone plume.

→Model results are generally as good or better than previous modeling efforts

We conclude:

→ the modelling system is fit for its intended purpose

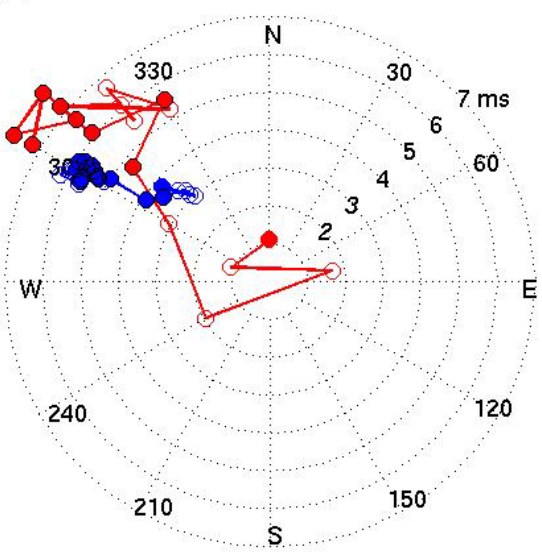
LFV ozone-precursor relationships

- Select a single episode from each circulation type
- Run CMAQ with 1985 and 2005 emissions under each circulation type to examine spatial evolution of ozone plume
- Perform precursor sensitivity test in order to diagnose ridgeline using indicators

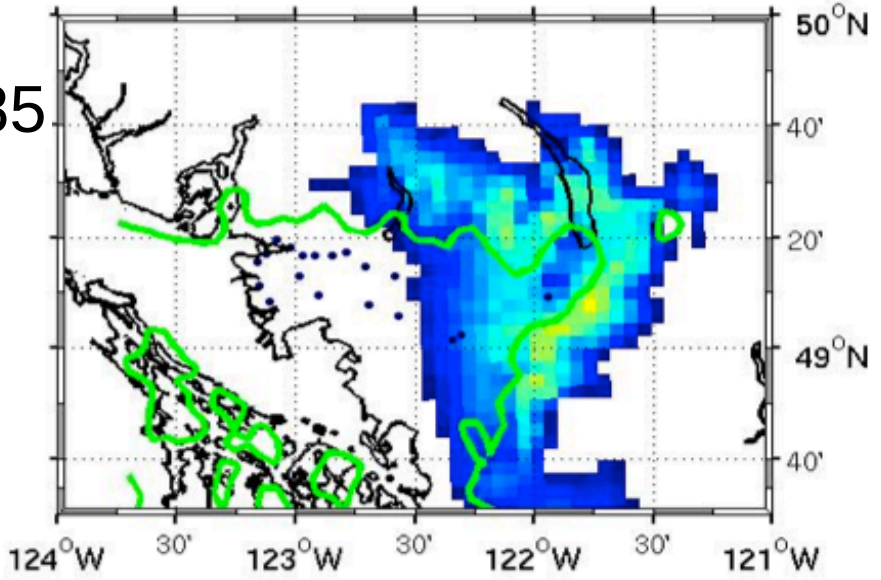
Type I Meteorology

Flow at YVR down GS with some associated return (offshore) flow

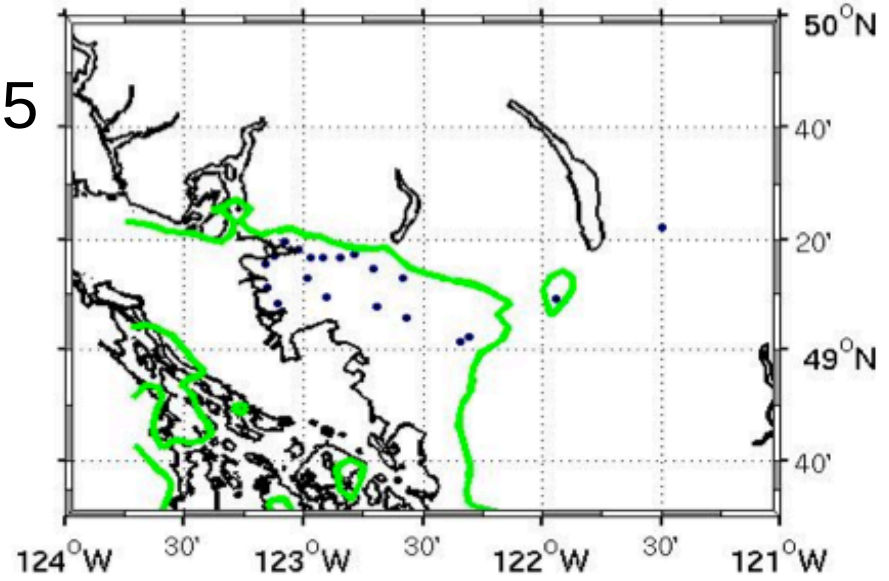
Ozone plume east Vancouver mid-valley

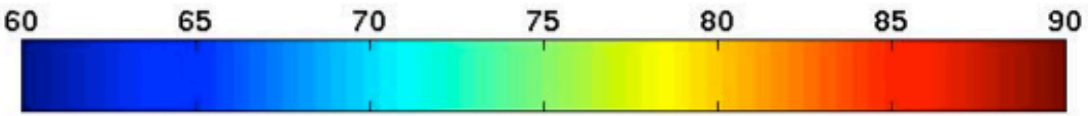


1985



2005

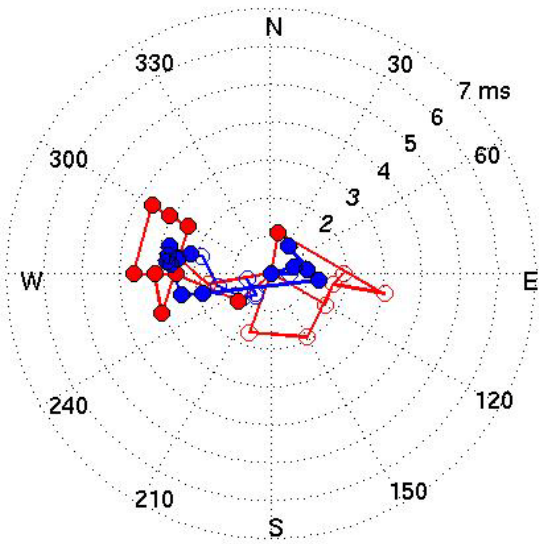




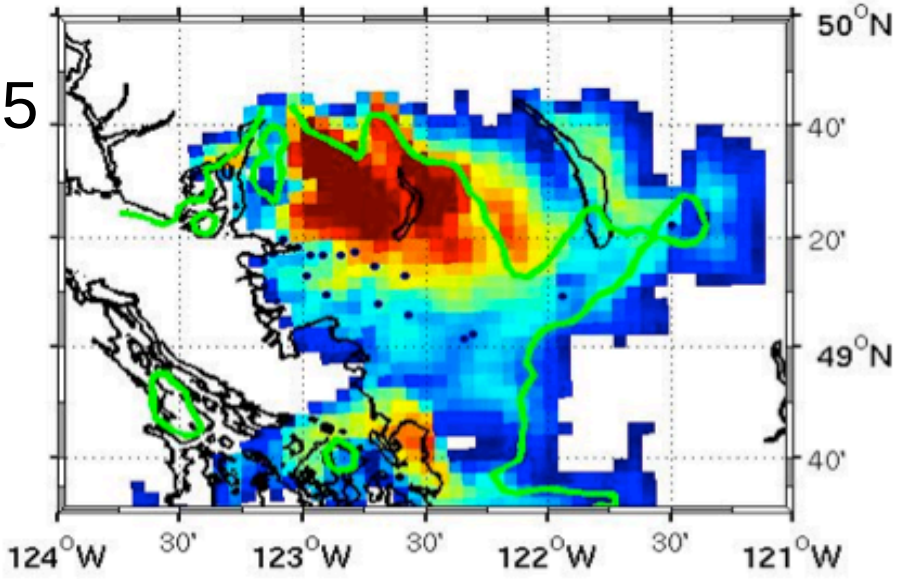
Type II Meteorology

Flow at YVR up JdF with light associated return (offshore) flow

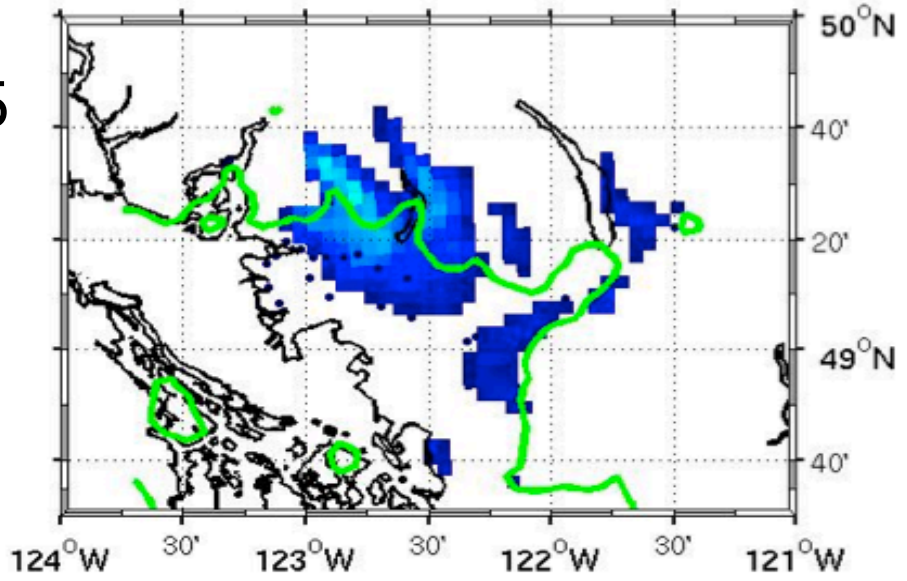
Ozone plume north and east of Vancouver over North Shore mountains

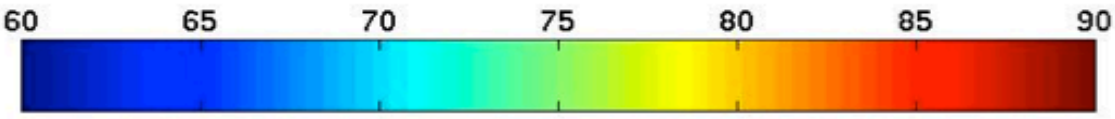


1985



2005

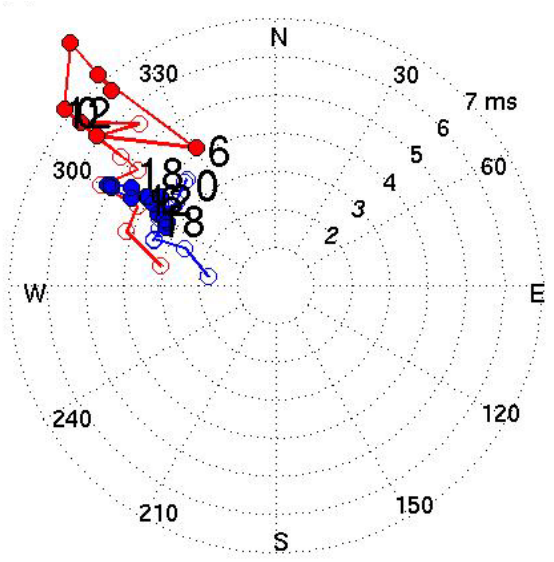




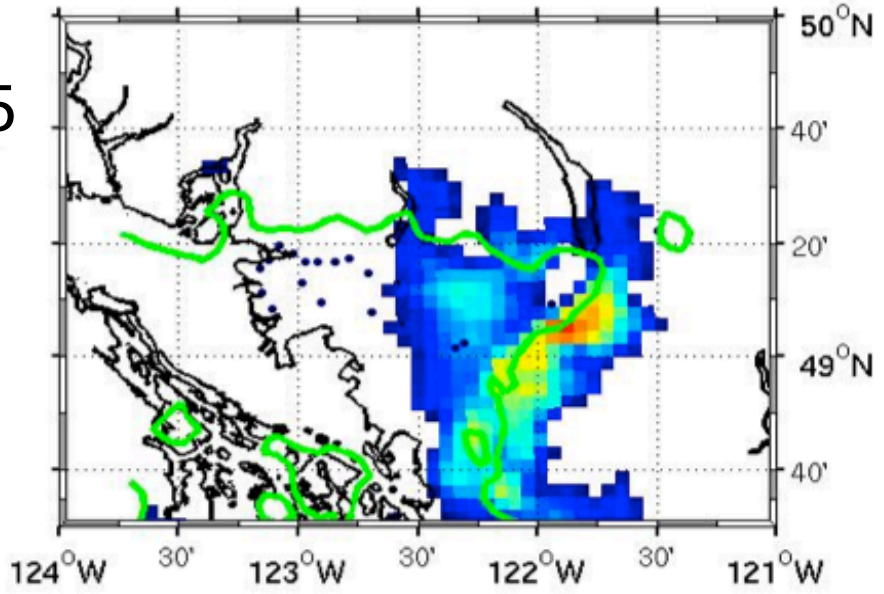
Type III Meteorology

Flow at YVR down GS with no return (offshore) flow

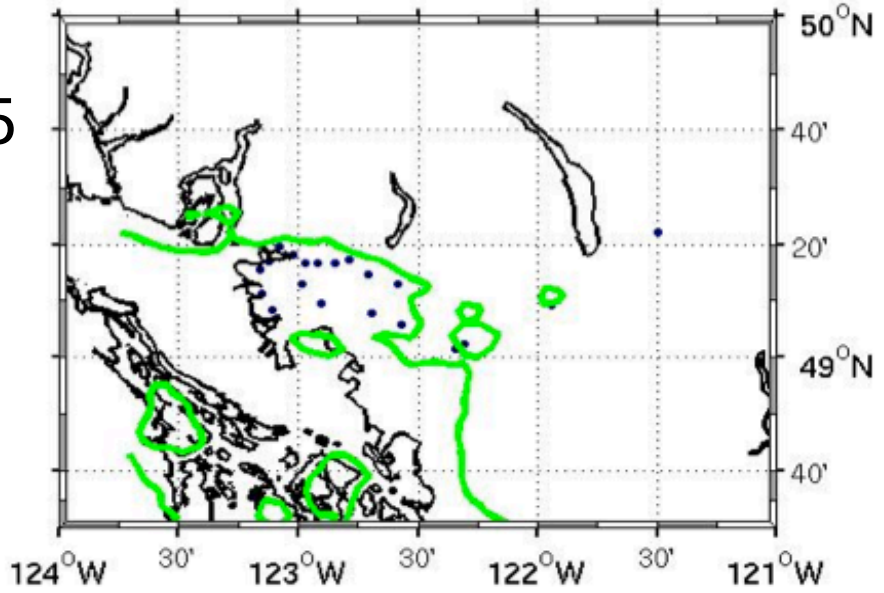
Ozone plume east of Vancouver over Cascade mountains

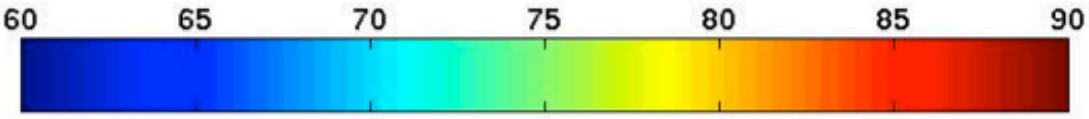


1985



2005

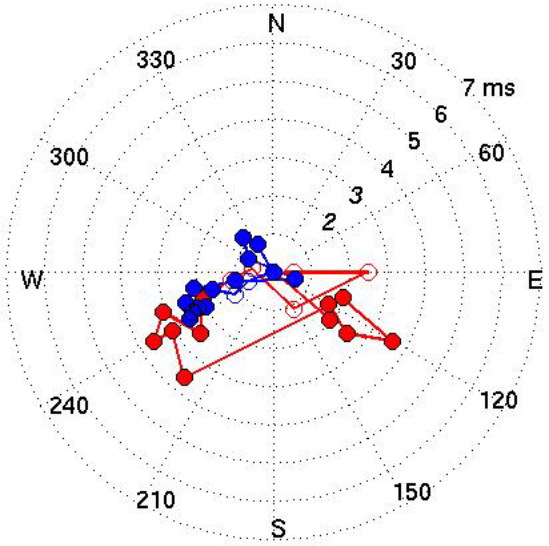




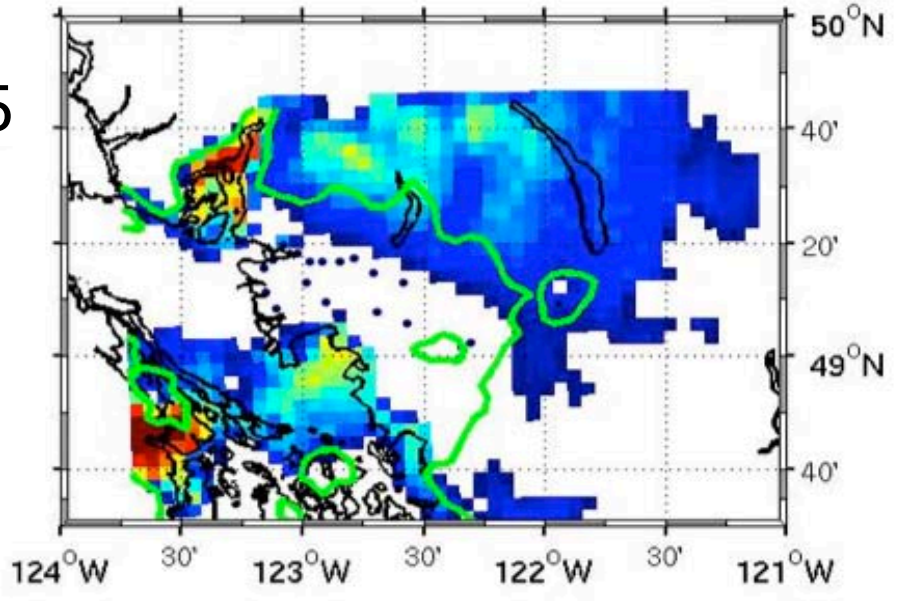
Type IV Meteorology

Flow at YVR up from JdF with some return (offshore) flow

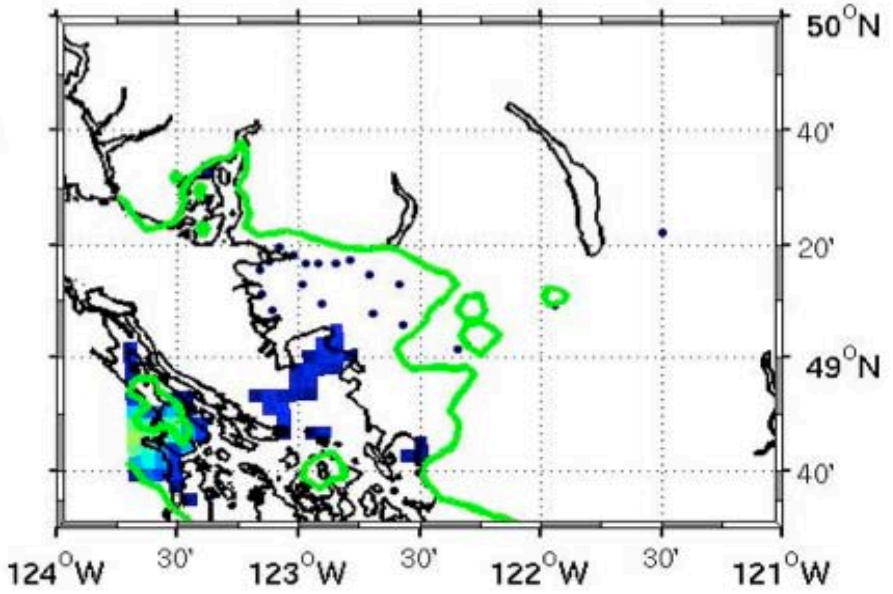
Ozone plume pushed out up Howe Sound away from Vancouver

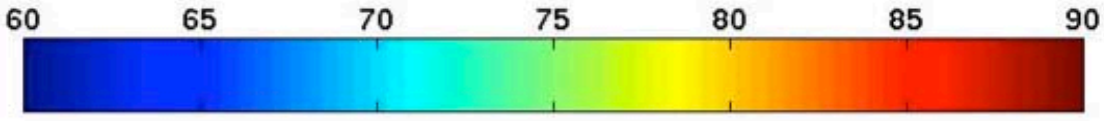


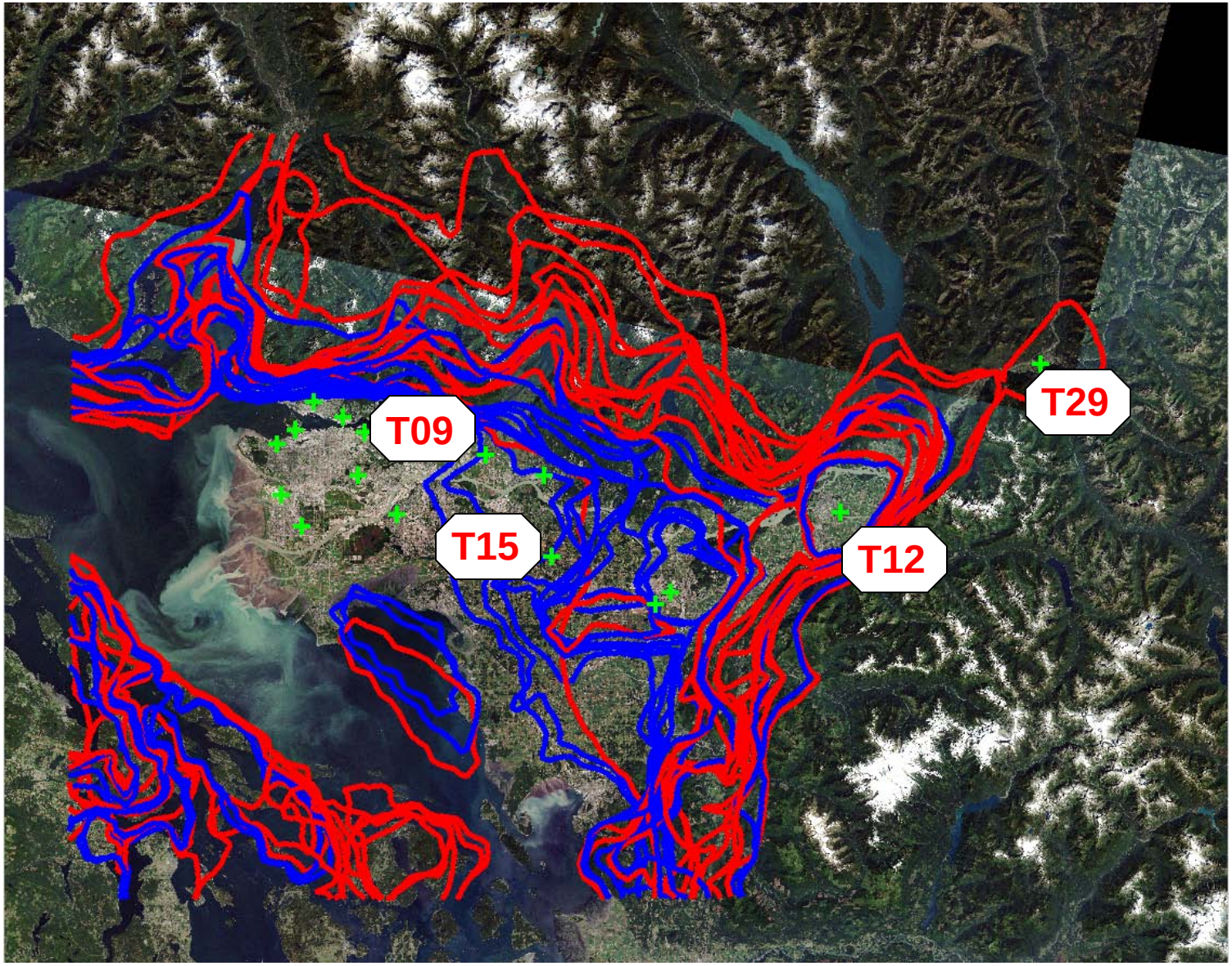
1985



2005







1985 emissions (red) -- 2005 emissions (blue)

Policy Findings

Western part of the valley (T09 and T15) has been and remains VOC-sensitive.

Mid-valley (T12) has gone from VOC-limited to NOx-limited.

Eastern most part of LFV (T29) has been, and remains a NOx-limited.

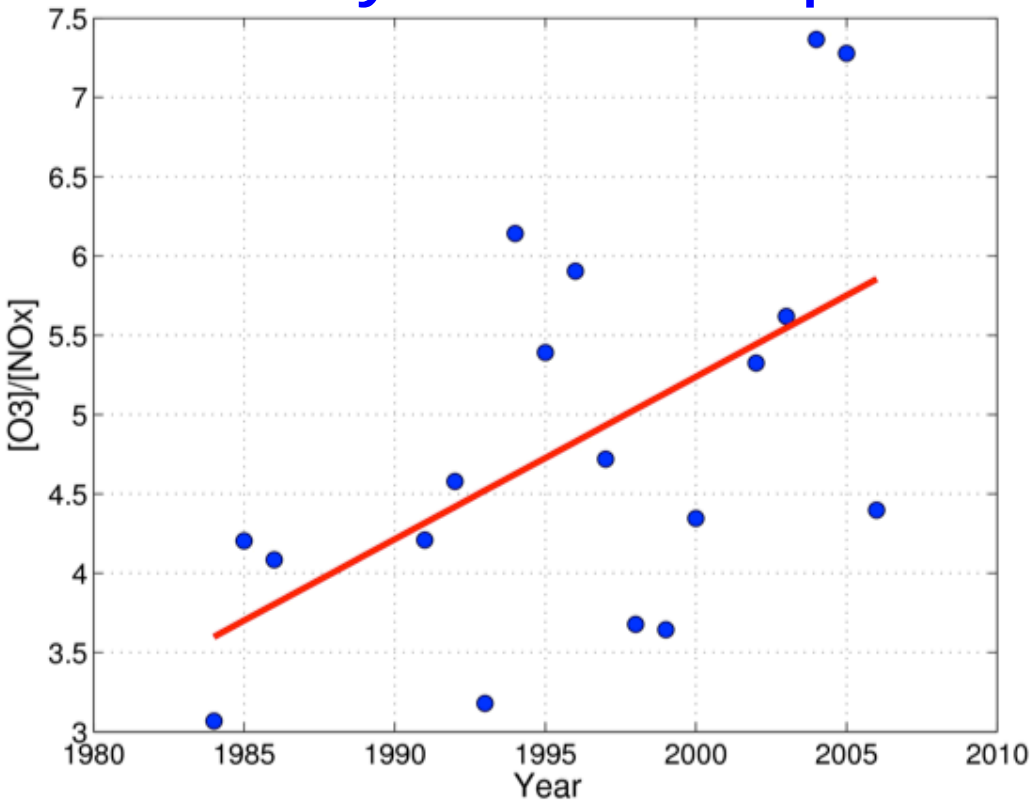
VOC emission reductions have been effective in reducing ozone concentrations in the western part of the valley, but these have been partly offset by NOx emissions reductions.

VOC emission reductions have likely had little effect in the eastern part of the valley

Emission Reductions Don't Tell the Whole Story

- Based on observations, rate of ozone production per NO molecule has increased between 1985-2005
- This has likely offset some of the NOx emission reductions.
- Observations show that these efficiency gains have been greater at T12 than T09
- Modelling also shows increased NOx-efficiency but increases appear to be uniform across the valley

NOx efficiency for ozone production



- 8-hr average [O_3]/[NOx] ratios from 1984 to 2006 (blue dots) at Chilliwack (T12), with trend line (red). (8-hr averages of the seven days with the highest hourly ozone concentrations in each year)
- This increase has offset benefits resulting from NOx reduction especially in the eastern part of the valley

Summary

- VOC emission reductions (especially mobile and refineries) have been effective in reducing ozone concentrations in the western part of the valley
- VOC emission reductions have likely had little effect in the eastern part of the valley
- NOx reductions have likely been offset by increased NOx efficiency
- Diurnal profiles have changed leading to higher 8hr averages relative to peak 1-hr average concentrations

Caveats

- Modelled ozone consistently over-predicted at a number of stations within the city of Vancouver
- Daytime NOx is consistently under-predicted within the city as well
- Model tends to under-predict ozone concentrations at the eastern most portion of the LFV

  ➔consistent with a deficiency in NOx emissions
- Model shows a slight changing ozone bias over time.

  ➔uncertainties in the emissions backcasting

Acknowledgements

- Metro Vancouver (AQ data, support to BC Clean Air Research Fund)
- Fraser Basin Council and Fraser Valley Regional District (support to BC Clean Air Research Fund)
- NSERC (grants to D. Steyn and P. Jackson)

More details – Submitted to Atmosphere-Ocean:

A retrospective analysis of ozone formation in the Lower Fraser Valley, British Columbia, Canada. Part I: Dynamical Model Evaluation

A retrospective analysis of ozone formation in the Lower Fraser Valley, British Columbia, Canada. Part II: Influence of emissions reductions on ozone formation