

Quantifying Regional GHG Emissions from Atmospheric Measurements: HFC-134a at Trinidad Head

A. Manning (1) and R. F. Weiss (2)



Abstract

Top-down approaches to emissions analysis provide a method of assessing bottom-up emission inventories and thus can be used for independent verification of submitted inventory values. In the example shown here, western US emissions of the greenhouse gas (GHG) HFC-134a are estimated using ground-based observations (Trinidad Head), an atmospheric dispersion model (NAME), and an inversion methodology.

This method can be extended to utilise observations from multiple stations and for many more gases of interest. Using more data from different geographical locations improves the ability of the inversion process to estimate both the magnitude and the distribution of the emissions.

Observations

High quality, high frequency observations of a range of greenhouse and ozone-depleting gases have been recorded at Trinidad Head (on the Northern California coast at 41°N, 124°W) as part of the 5-station global AGAGE (Advanced Global Atmospheric Gases Experiment) network (Prinn et al 2000), all now utilising a combination of automated multi-detector gas chromatographs, and the new state-of-the-art *Medusa* automated gas chromatograph/mass spectrometer (GC-MS) instrument system, which preconcentrates and cryofocusses approximately 40 trace gases from 2-litre air samples prior to separation on a capillary column and MS detection.

The HFC-134a measurements modelled here were made by the Trinidad Head *Medusa* at 2-hourly intervals, with a relative precision of 0.4%. HFC-134a (CH₂FCF₃) is the preferred replacement for the ozone-depleting compound CFC-12 (CCl₂F₂) in refrigeration and air conditioning applications.

Atmospheric Dispersion Modelling

The NAME atmospheric dispersion model (Ryall et al 1998, Jones et al 2004) has been used to estimate the recent history of the air that arrives at the Trinidad Head observing station. The NAME model is a Lagrangian model that is used in the UK for a wide range of atmospheric dispersion applications such as; emergency response (Witham et al 2007, Webster et al 2006) and estimating emissions (Greally et al 2007, Manning et al 2003, Reimann et al 2005).

In this study the NAME model has been driven by 3D analysis meteorology from the UK Met Office. Over the duration of this study the resolution of the meteorology has improved, in December 2005 it changed from a horizontal resolution of ~55km to ~40km, the number of vertical levels remained constant at 33 (most in the lower levels but extending to 20km).

For each 3-hour period Mar. 2005 until June 2007 the NAME model has been used to estimate the recent (10 day) history of the air arriving at Trinidad Head. Figure 1 shows two examples of the 3-hour maps that are generated, one from a 'clean' sector and one from a 'polluted' sector.

Using the 3-hour maps of air history, the number of times each area (grid box ~40km) contributes to the air concentration at Trinidad Head in each month (Jan 2006 – Dec 2006) has been calculated. Figure 2 shows the results from two months, June and December. From these maps it is clear that in the spring months Trinidad Head only poorly samples the southern half of California.

The 3-hour air history maps can be used to classify the air masses at Trinidad Head. Baseline or background air is defined as those times when the air predominantly comes straight from the Pacific Ocean and represents the mid-latitude Northern Hemisphere baseline concentration. Times when the air is slow moving or not well mixed over the observing station are classed as being locally influenced and are excluded from the baseline category.

Baseline Concentrations

The average monthly baseline concentrations can be estimated through this method. The baseline values for HFC-134a from Trinidad Head have been compared against those at Cape Grim in Australia and Mace Head in Ireland (Figure 3). Those values estimated from the Trinidad Head station are very closely aligned with those from a similar station at Mace Head on the west coast of Ireland. Due to the distribution of the sources of HFC-134a and the time lag in air moving across the tropics, the baseline estimated from Cape Grim in Australia is significantly lower than those in the Northern Hemisphere.

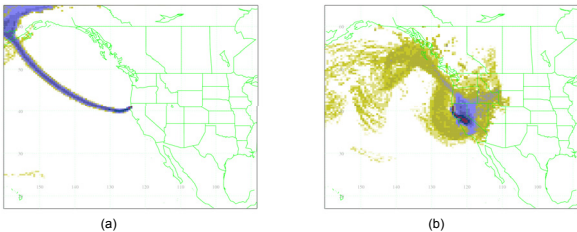


Figure 1: Example air history maps for Trinidad Head (a) Clean air masses (b) Polluted air masses

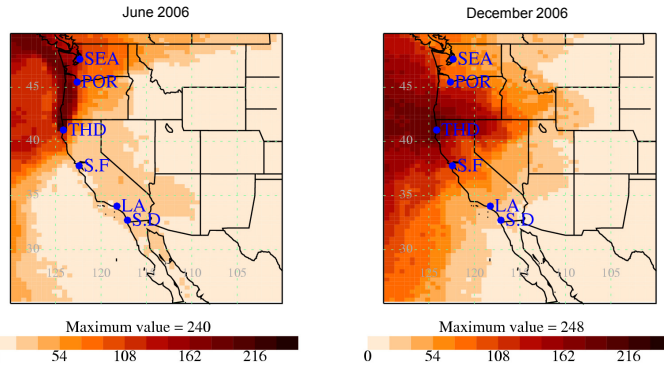


Figure 2: Number of times each ~40km grid box contributed to the air at Trinidad Head (THD) in June and December, 2006

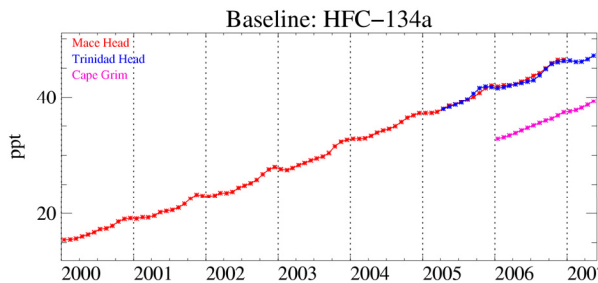


Figure 3: Monthly baseline values of HFC-134a at 2 AGAGE stations in the Northern Hemisphere (Trinidad Head, USA, and Mace Head, Ireland) and one in the Southern Hemisphere (Cape Grim, Australia).

Estimating Regional Emissions

The NAME air history maps provide information on how much material is transported from each area to the observing site. The observed concentration is a combination of the baseline value and the impact of regional emissions. The deviation of the observations from the baseline concentration is an indication of the strength of the regional emissions upwind of the observation. By applying the inversion method as discussed in Manning et al 2003 the regional emissions of any trace gas can be estimated. Figure 4 shows the estimated emissions of HFC-134a for the area surrounding Trinidad Head.

The population of the five western US states (California, Washington, Oregon, Nevada, and Idaho) covered in Figure 4 is around 50 million people, which is approximately one sixth of the population of the US. Assuming the emissions of HFC-134a are relatively constant per head of US population, it is estimated that the US emission of HFC-134a for 2006 is 43kt (uncertainty range: 22-60 kt).

The emission map shown in Figure 4 picks out most of the significant populated areas and estimates very low emissions from the ocean areas. This is consistent with the understanding that HFC-134a is emitted broadly in line with population as it is a widely used refrigerant that is emitted primarily from air conditioners in cars.

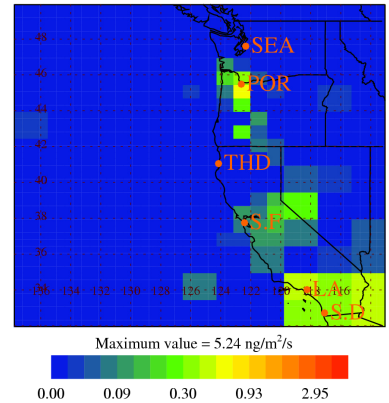


Figure 4: Emission estimate of HFC-134a for 2006. Locations are shown for the Trinidad Head (THD) measurement site and for major cities on the US west coast.

Discussion

The geographical location of an observing site is very important. If an observing station sometimes receives air from 'clean' baseline sectors and sometimes from 'polluted' sectors it is possible to estimate the regional emissions of the gases measured. The inversion methods used to estimate these emissions rely on correct 3D meteorological fields especially close to the observing site. The ability of numerical weather prediction models to estimate the flow in areas of significant orography is very dependant on the resolution of the models used.

The Trinidad Head station is well placed to estimate the emissions from Northern California, Oregon and Washington as it frequently receives air from these areas. This observing site only very rarely receives air from Nevada and the southern half of California and so is less able to estimate emissions from these areas. Additional observing station(s) further to the south, in conjunction with Trinidad Head, would enable the whole of California to be sampled thus improving the emission estimates. To be most effective it is important that any additional station(s) is not too close to significant emission sources (observed signal is dominated by local sources) or to significant orography (numerical 3D meteorological models do not represent these areas well).

The methods presented here can be used to verify emissions of all measured GHGs and their changes over time. This top-down approach is particularly useful in providing estimates of gases whose sources are less well understood. These methods have been configured to readily accept information from multiple stations, which has been shown to significantly reduce the uncertainties in the estimates.

Greally B.R., Manning A.J. et al., 'Observations of 1,1-difluoroethane (HFC-152a) at AGAGE and SOGE monitoring stations in 1994-2004 and derived global and regional emission estimates', *Journal of Geophysical Research* 112, D06308, 2007

Jones A.R., Thomson D.J., Hort M. and Derwentish B., 'The U.K. Met Office's next-generation atmospheric dispersion model, NAME III', submitted to Proceedings of the 27th NATO/CCMS International Technical Meeting on Air Pollution Modelling and its Application, 2004

Manning A.J., Ryall D.B., Derwent R.G., Simmonds P.G. and O'Doherty S., 'Estimating European emissions of ozone-depleting and greenhouse gases using observations and a modelling back-attribution technique', *J. Geophysical Research* 108, 4405, 2003

Prinn R. G., Weiss R.F., et al. 'A history of chemically and radiatively important gases in air deduced from ALE/GAGE/AGAGE', *Journal of Geophysical Research* 105, 17,751-17,792, 2000

Reimann S., Manning A.J., Simmonds P.G., Cunlind D.M., Wang R.H.J., Li J., McCulloch A., Prinn R.G., Huang J., Weiss R.F., Fraser P.J., O'Doherty S., Greally B.R., Stemmeler K., Hill M. and Folini D., 'Low European methyl chloroform emissions inferred from long-term atmospheric measurements', *Nature* 433, 506-508, 2005

Ryall D.B. and Mayron R.H., 'Validation of the UK Met Office's NAME model against the ETEX dataset', *Atmospheric Environment* 32, 4265-4276, 1998.

Webster H.N., Abel S.J., Taylor J.P., Thomson D.J., Haywood J.M. and Hort M.C., 'Dispersion Modelling Studies of the Buncefield Oil Depot incident', *Hadley Centre Technical Note* 69, Met Office, August 2006

Wilham C.S., Hort M.C., Potts R., Servranckx R., Husson P. and Bonaerodot F., 'Comparison of VAAC atmospheric dispersion models using the 1 November 2004 Grimsvötn eruption', *Meteorological Applications* 14, 27-38, 2007