Using Inverse Modelling to Investigate Potential IR Measurement Strategies for Constraining the Australian Carbon Cycle

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INTRODUCTION

This study employs a top-down approach to better understanding the carbon cycle. Fourier Transform Spectroscopic trace gas measurements are combined with inverse modelling. Possible measurement locations and strategies in the Australian continent are investigated. This is done by simulating data for the potential measurement locations, and using this simulated pseudodata in inversion studies to determine the additional constraint applied to the source estimate uncertainty in Australia and nearby regions.

OCO Satellite Program

Orbiting Carbon Observatory
Aim – Global CO_2 coverage
Near InfraRed (NIR) Spectrometers
Launch – 2008
http://oco.jpl.nasa.gov

Total Carbon Column Observing Network (TCCON)

- Park Falls, Wisconsin
- **Darwin, Australia**
- Lauder, New Zealand
- Lamont, Oklahoma
- Bremen, Germany
- Ny Alesund, Norway

\+ other potential future sites

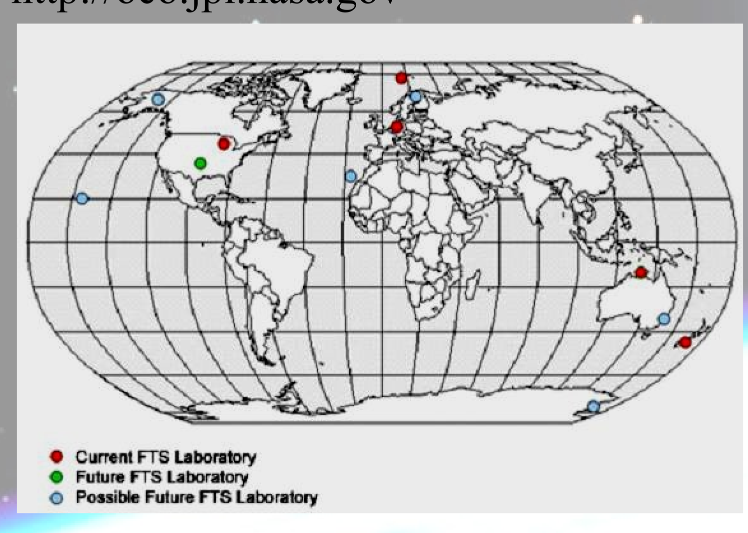


Fig. 1. Map showing current, future and possible future total column FTS observatories in TCCON.

METHOD

Atmospheric Trace Gas Measurement by Fourier Transform Spectrometry

Two distinct types of atmospheric trace gas measurements by Fourier Transform Spectrometry (FTS) are used in this study. The first is solar remote sensing, which involves observing total column amounts through the atmosphere is well established [Washenfelder *et al*, 2003, Yang *et al*, 2002], and involves high spectral resolution infrared measurements extending into the Near InfraRed (NIR). This high precision method will be used as part of the Total Carbon Column Observing Network (TCCON), and include an instrument located in Darwin, Australia. The second is a low spectral resolution *in situ* technique, resulting in high precision simultaneous measurements of CO_2, CH_4, N_2O and CO on sub hour timescales [Esler *et al*, 2000]. The nature of these measurements taking place at Darwin, in conjunction with the TCCON instrument, and along the Ghan railway, which runs from Adelaide to Darwin, are being pursued.

Solar FTS Remote Sensing

- Hi-Res Fourier Transform Spectrometer (Bruker IFS125HR) – coupled to solar tracker
- Sun - black body source
- 2000-15800 cm^{-1} coverage
- Total column mean CO_2 mole fractions (X_{CO2})
- OCO validation instruments
- CH_4, CO, N_2O, O_2

Fig. 2. (right) FTS validation laboratory in Darwin, Australia

In Situ FTS

- OOOFTI (One Of Our FT Instruments)
- Low (spectral) resolution FTS (Bomem MB100/Bruker IRCube)
- Internal source
- Cell coupled to spectrometer
- Continuous flow (~1L/min) of air from ~10m above surface
- CO_2, CH_4, N_2O, CO, $^{13}CO_2$

- Lauder, New Zealand
- Darwin, Australia
- Ghan Railway, Australia

Fig. 3. An OOOFTI in Kyabram, Australia

Synthetic Bayesian Inverse Modelling

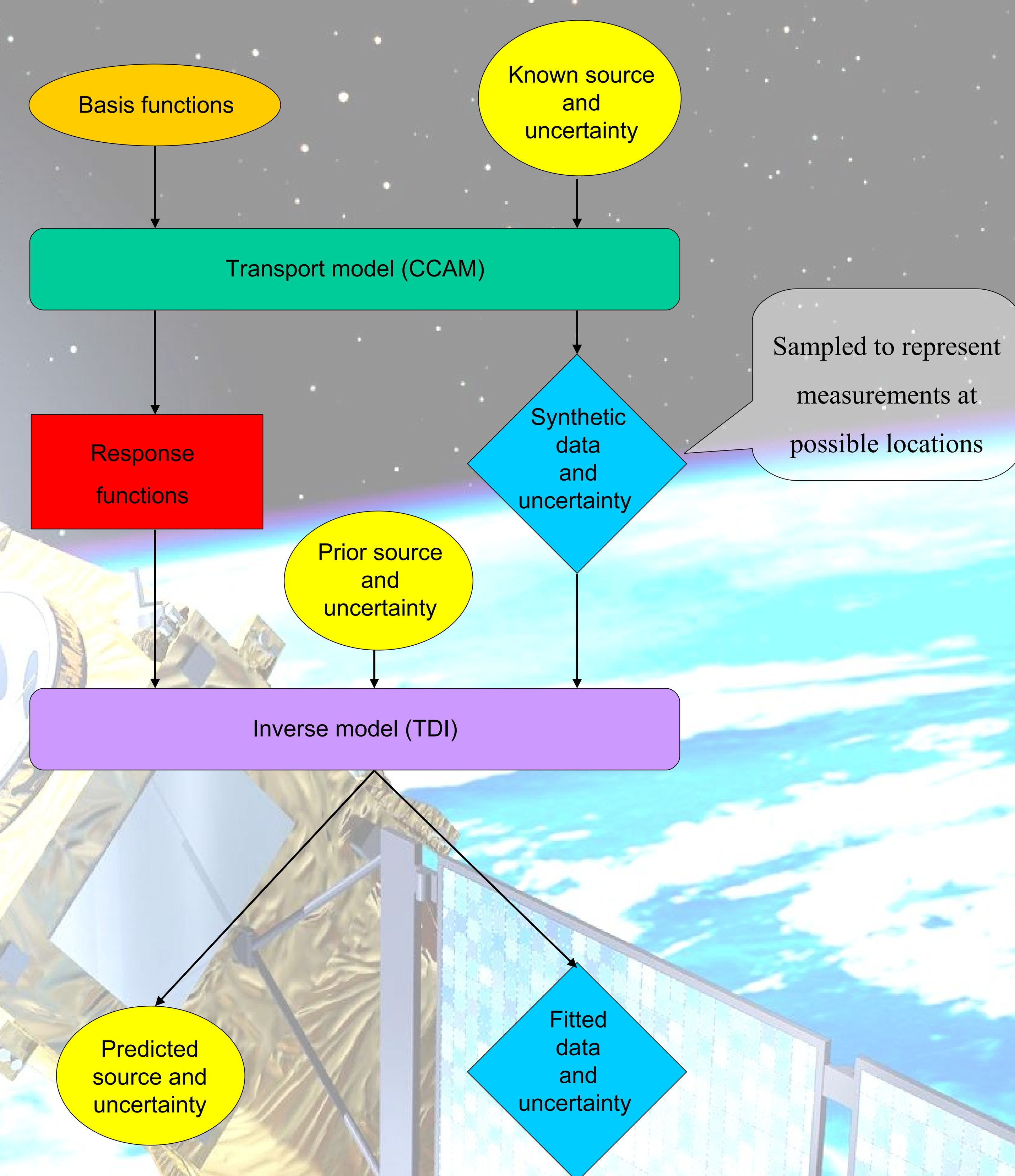


Fig. 4. Schematic diagram illustrating the synthetic inverse modelling process, from beginning (top) to end (bottom).

Fig. 5. The Ghan Railway travelling through central Australia.

Fig. 6. Train routes operated by Great Southern Railways – Ghan, Indian Pacific, and Overland. Image from http://www.perthtourist.com/english/indian_pacific_e.asp

- Constrain strength and distribution of global and regional atmospheric CO_2 fluxes
- CSIRO's Conformal Cubic Atmospheric transport Model (CCAM) – Forward model
  - Run 'known' fluxes to:
    - Generate response functions (change in concentration at locations due to flux changes)
    - Create synthetic (pseudo) data (time series of concentration data at locations of interest)
      - Cape Grim
      - All points on Ghan railway
- Time Dependent Inverse (TDI) model – Inverse model
  - Basic network (40 sites – GLOBALVIEW-CO_2 [2004] + synthetic continuous Cape Grim data)
  - Additional synthetic data

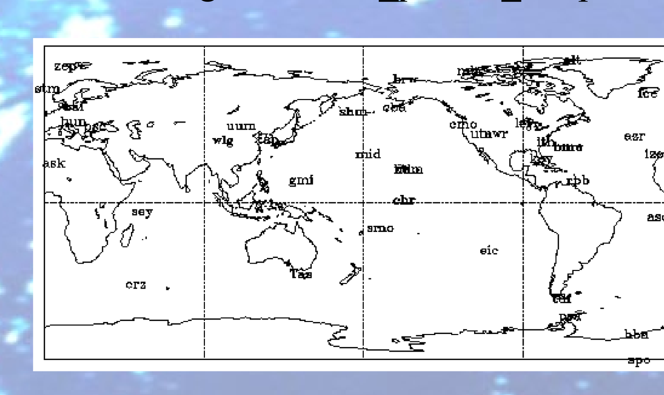
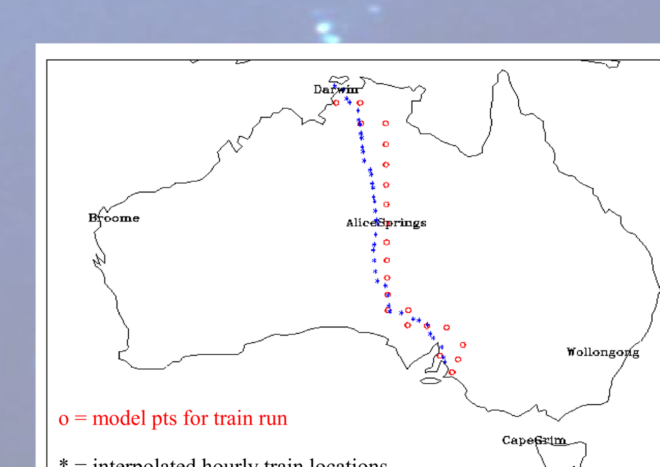


Fig. 7. (a) The basic network of 40 sites. (b) Australian sites of interest



RESULTS AND DISCUSSION

Addition of continuous data at Darwin reduces flux uncertainties in the region surrounding Darwin to less than 20% of previous estimates, as well as providing constraints on neighbouring regions. The Ghan Railway transect provides stronger constraints than Darwin measurements on all the regions through which the railway passes, excepting the northernmost central region which includes Darwin. Together the Ghan Railway transect and Darwin provide significant uncertainty reduction on close to half the Australian continent. The unimproved uncertainty in the large central region is due to the small initial uncertainty applied to that region because of its relative uniformity and desert nature. These estimates are purely theoretical, and assume the data are obtained continuously, and are representative of the location's model grid cell. As a result, the uncertainty reductions obtained will probably be less than those estimated by this synthetic inverse study. However, the results here are encouraging for the potential value of future data.

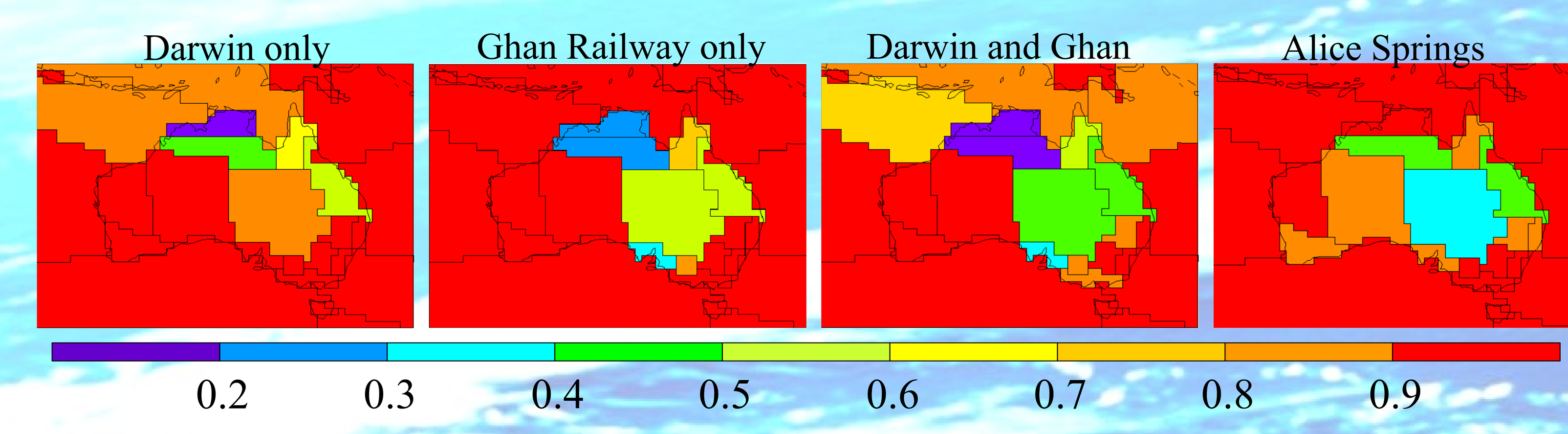


Fig. 8. Relative uncertainty from the addition of *in situ* FTIR measurements at various locations. The contours represent the ratio of the predicted uncertainty from the inversion including the synthetic data for the named location to the uncertainty predicted from an inversion with a base network of sites.

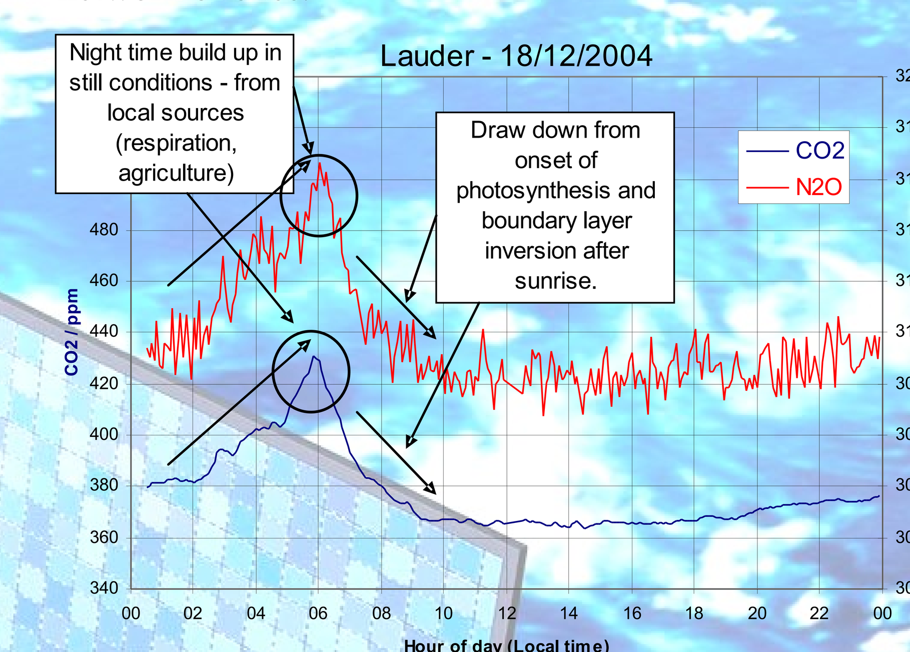


Fig. 9. Sample data from one day's OOOFTI collection at Lauder, NZ. Included on the plot are time series for CO_2 and N_2O

FUTURE DIRECTIONS

- Ghan railway
  - Measurement frequency
  - Indian-Pacific (Sydney-Perth) & Overland (Melbourne-Adelaide)
- Multi-species inversions (make use of CH_4, CO, N_2O, $^{13}CO_2$ data)
  - As tracer for CO_2 source type
  - More advanced?
- Column inversions (a long way off yet)
- Measurements
  - Lauder (since late 2004)
  - Darwin (late 2005)
  - Ghan railway (early 2006)
- Replace synthetic data with data from measurements

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REFERENCES:

- Esler, M.B., D.W.T. Griffith, S.R.Wilson, and L.P. Steele (2000), Precision Trace Gas Analysis by FT-IR Spectroscopy. 1. Simultaneous Analysis of CO_2, CH_4, N_2O, and CO in Air, *Anal. Chem.*, 72(1), 206-215.
- GLOBALVIEW-CO_2: Cooperative Atmospheric Data Integration Project - Carbon Dioxide. CD-ROM, NOAA CMDL, Boulder, Colorado [Also available on Internet via anonymous FTP to ftp.cmdl.noaa.gov, Path: ccg/co2/GLOBALVIEW], 2004.
- Washenfelder, R.A., P.O. Wennberg and G.C. Toon (2003), Tropospheric methane retrieved from ground-based near-IR solar absorption spectra, *Geophys. Res. Lett.*, 30, L017969, doi:10.1029/2003GL017969
- Yang, Z., G.C. Toon, J.S. Margolis and P.O. Wennberg (2002), Atmospheric CO_2 retrieved from ground-based near IR solar spectra, *Geophys. Res. Lett.,* 29, L014537, doi:10.1029/2001GL014537

Background image taken from: http://esamultimedia.esa.int/images/EarthObservation/03947A4.jpg