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Using IASI and MIPAS in combination to characterise CO and other volatile organic compound emissions from fires

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3rd IASI INTERNATIONAL CONFERENCE

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Introduction

- **Short-lived species emitted from wildfires carry a lot of information on atmospheric processes relating to chemistry, convection and emissions.**
- **These disruptive events are, indirectly, a climatological feature of the Earth's atmosphere and its climate response**
  - These events **occur at sufficient frequency** to make studying and understanding biomass plume chemistry vital
  - Benefit improvements in climate/chemistry models through measurements

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- **Fires: 2 case studies**
  - Black Saturday (February 2009)
    - Using MIPAS and IASI to aid trace gas retrievals
  - BORTAS aircraft campaign - Impact of boreal forest fires on Tropospheric oxidants over the Atlantic (July/August 2011
    - Comparisons of IASI to in-situ data (HCOOH)

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Introduction

- **Suite of species we observe with MIPAS and IASI** provide information on biomass burning and plumes including:
  - Plume composition and chemistry
  - Intercontinental transport

Biomass

Species	Instrument	Spectral range [cm^{-1}]	Feature	Source	Importance	Reference
PAN	**MIPAS (and IASI in high cases)**	775- 800	Broad	Secondary pollutant	Ozone production in remote regions	Moore et al., ACP, 2010
Acetone	**MIPAS**	1215 -1220	Broad	Biomass burning/ biogenic	Upper tropospheric source of OH	Moore et al., ACP, 2012
CO	**MIPAS and IASI**	2169.25 – 2175.25	Series of Lines	Biomass burning	Removal of OH, indirectly increasing lifetime of GHGs (i.e. CH_4)	Illingworth et al., 2011
C_2H_2	**MIPAS and IASI**	766 – 767	Strong line	Biomass burning	Role in glyoxal formation	Wiegele et al., 2012
C_2H_4	**IASI**	949 – 950	Strong line	Biomass burning	Good tracer of biomass burning	Herbin et al., GRL, 2009
HCN	**MIPAS and IASI**	747 – 748	Strong line	Biomass burning	Tracer of biomass burning	Glattor et al., ACP, 2009
HCOOH	**MIPAS and IASI**	1105 – 1105.25	Strong line	Vegetation	Contribute to acidity of precipitation	Grutter et al., JGR, 2010

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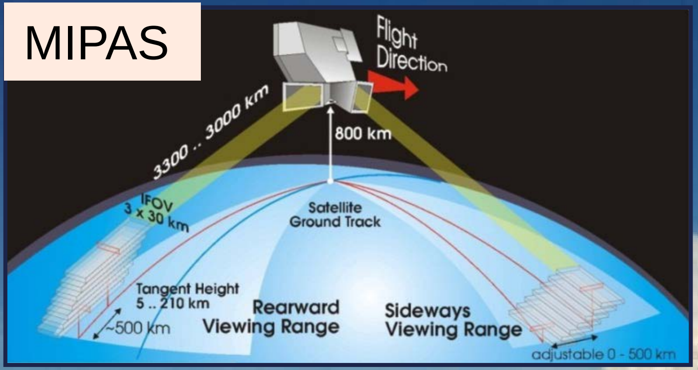
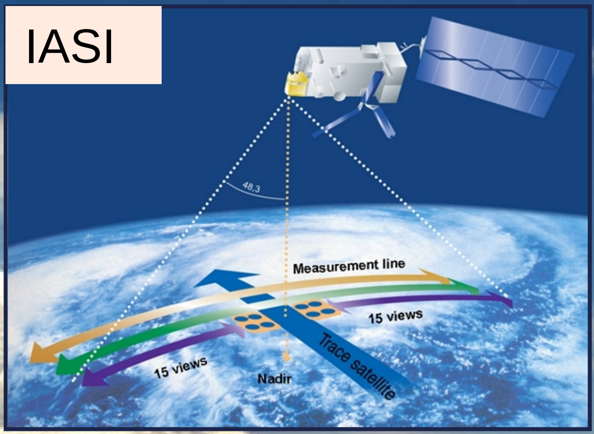
MIPAS and IASI instruments

MIPAS



IASI



MIPAS specifics	
Platform	ENVISAT
Instrument type	**Fourier Transform Spectrometer**
Mass	320 kg
Spectral range	**4.15 to 14.2 microns in 5 spectral bands (685-2410 cm^{-1})**
Spectral resolution	0.025cm^{-1} (March 2002-March 2004) 0.0625 cm^{-1} (August 2004-April 2012)
Vertical range	**6 to 68 km**
Vertical resolution	3 km from 6 to 42 km, 5 km from 42 to 52 km, 8 km from 52 to 68 km
Species measured	**L1b emission spectra - Potential to observe many gases** **L2 vertical profiles- operational products: H_2O, O_3,CH_4, N_2O, NO_2, HNO_3**

IASI specifics	
Platform	METOP
Instrument type	**Michelson Interferometer**
Mass	210 kg
Spectral range	**3.62 to 15.5 microns (645-2760 cm^{-1})**
Spectral resolution	0.5cm^{-1}
Species measured	**L1C emission spectra** **L2 vertical profiles- operational products: CO_2, N_2O, CFC-11, CFC-12, OCS, H_2O, O_3,CH_4, NH_3, CO, HNO_3, HCOOH, CH_3OH, SO_2**

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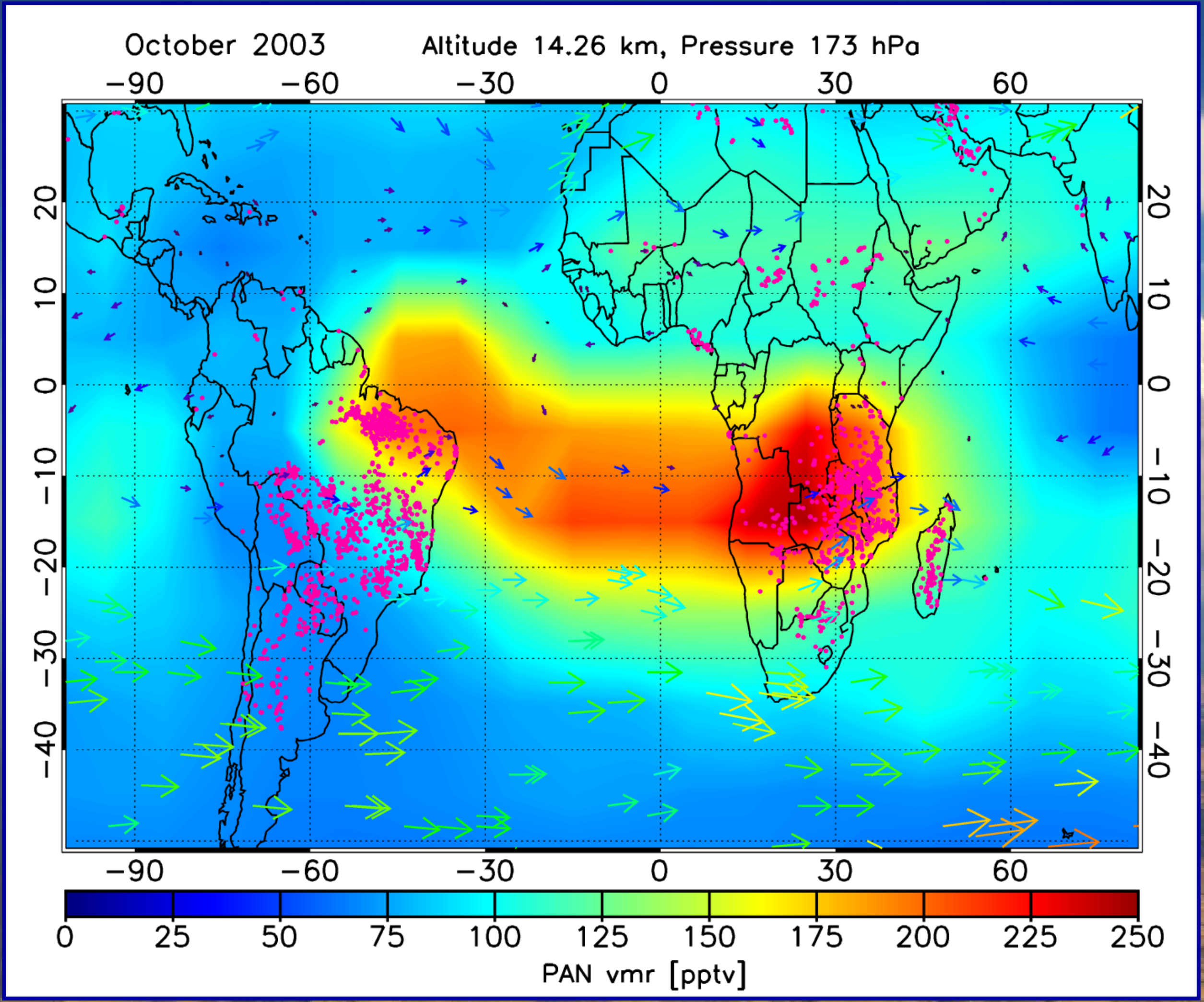
MIPAS - Peroxyacetyl nitrate



- PAN measurements during October 2003
- Transport of pollution across Southern Atlantic Ocean
- Large source
  - savanna fires over Southern Africa
- Taken from Moore et al., ACP 2010

Key:
Pink dots – AATSR fires
Arrows – ECMWF wind vectors

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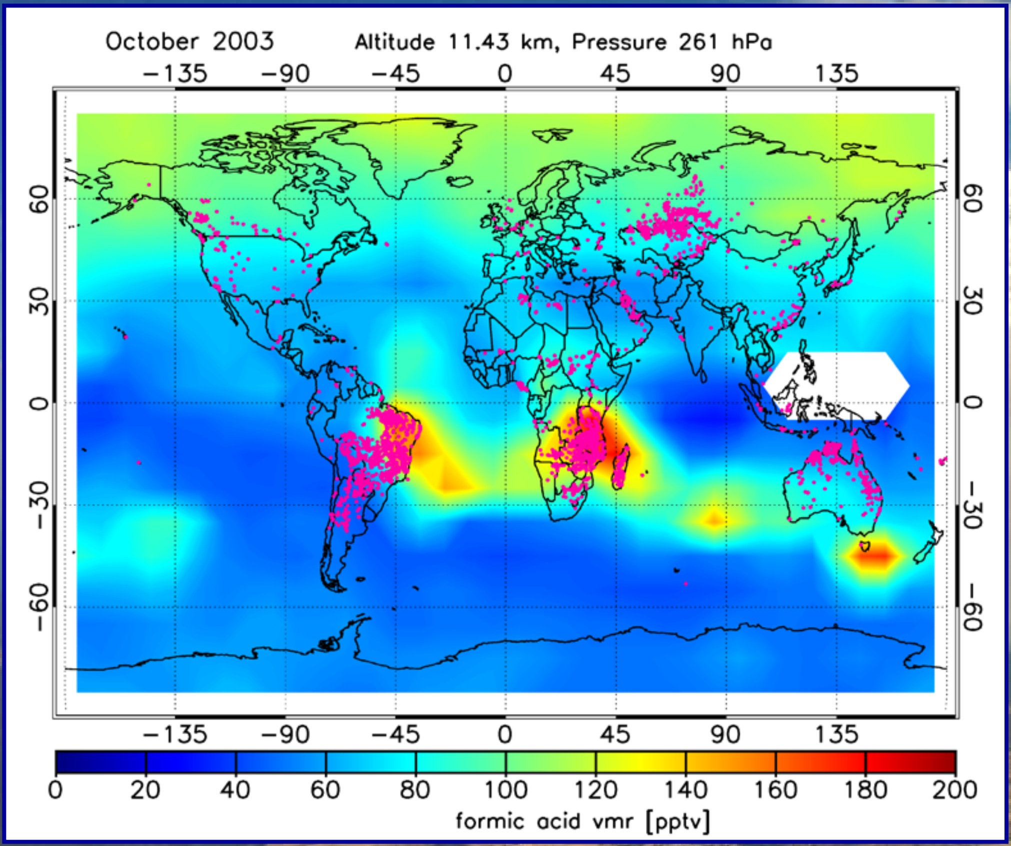
Formic acid from MIPAS – October 2003



- Captures outflow from South American and Southern Africa fires
- Long-range transport from source regions
- Data available for whole of 2003, 2008-2011

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IASI gas detection approach

Cloud-free IASI Brightness Temperature spectrum

BTD = peak/baseline

- **Brightness temperature differencing (BTD)**
- Use clear gas lines ("peak") which are largely free from contaminating species.
  - HCOOH 1105 cm^{-1}
  - HCN 747.5 cm^{-1}
  - C_2H_2 766.75 cm^{-1}
  - C_2H_4 949.5 cm^{-1}
- Find "baseline" regions either side of peak which is relatively clear of target gas AND with little influence of other highly variable gases (i.e. another biomass marker)

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ULIRS – University of Leicester IASI Retrieval Scheme

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Pre-process and Cloud Clear IASI Data

Get ECMWF T, Altitude and H_2O Profiles

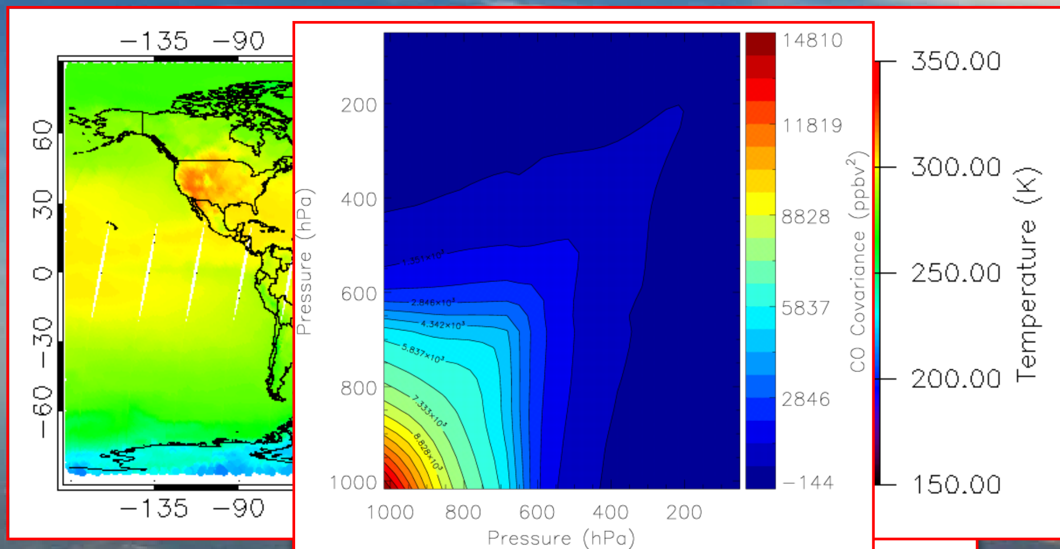
Get Surface Emissivity from CIMSS

Calculate a priori statistics from TOMCAT (for CO) or mix INTEX-B/ACE/MIPAS for organics.

Select Climatology

Perform OEM Retrieval Using Oxford RFM

Convert to Total Column Using DEM Data



Full details of ULIRS in Illingworth et al., AMT, 2011

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"Black Saturday" bush fires

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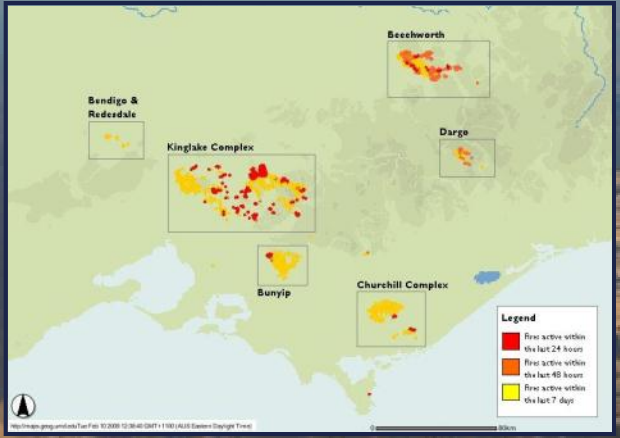
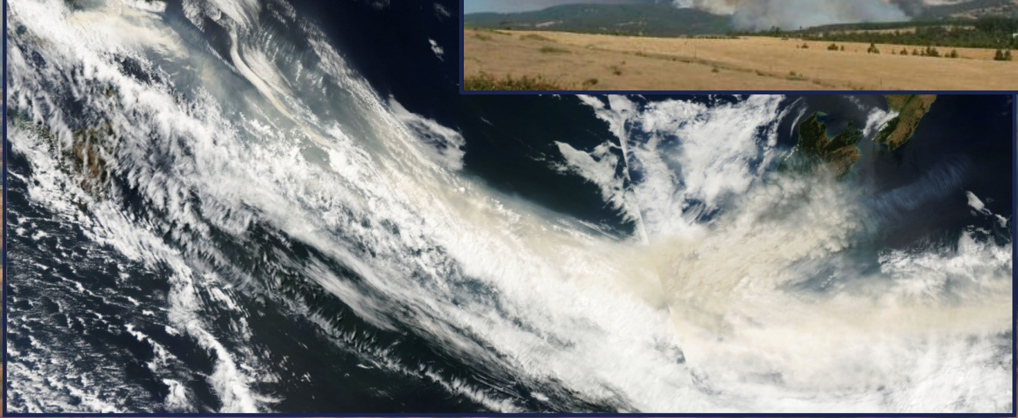
- A series of bushfires which started in South-Eastern Australia on February 7th 2009
- Over 450000 hectares burnt
- Fires burned over the period 7/2 – 14/3
- Other work determines stratospheric aerosol/gas injection





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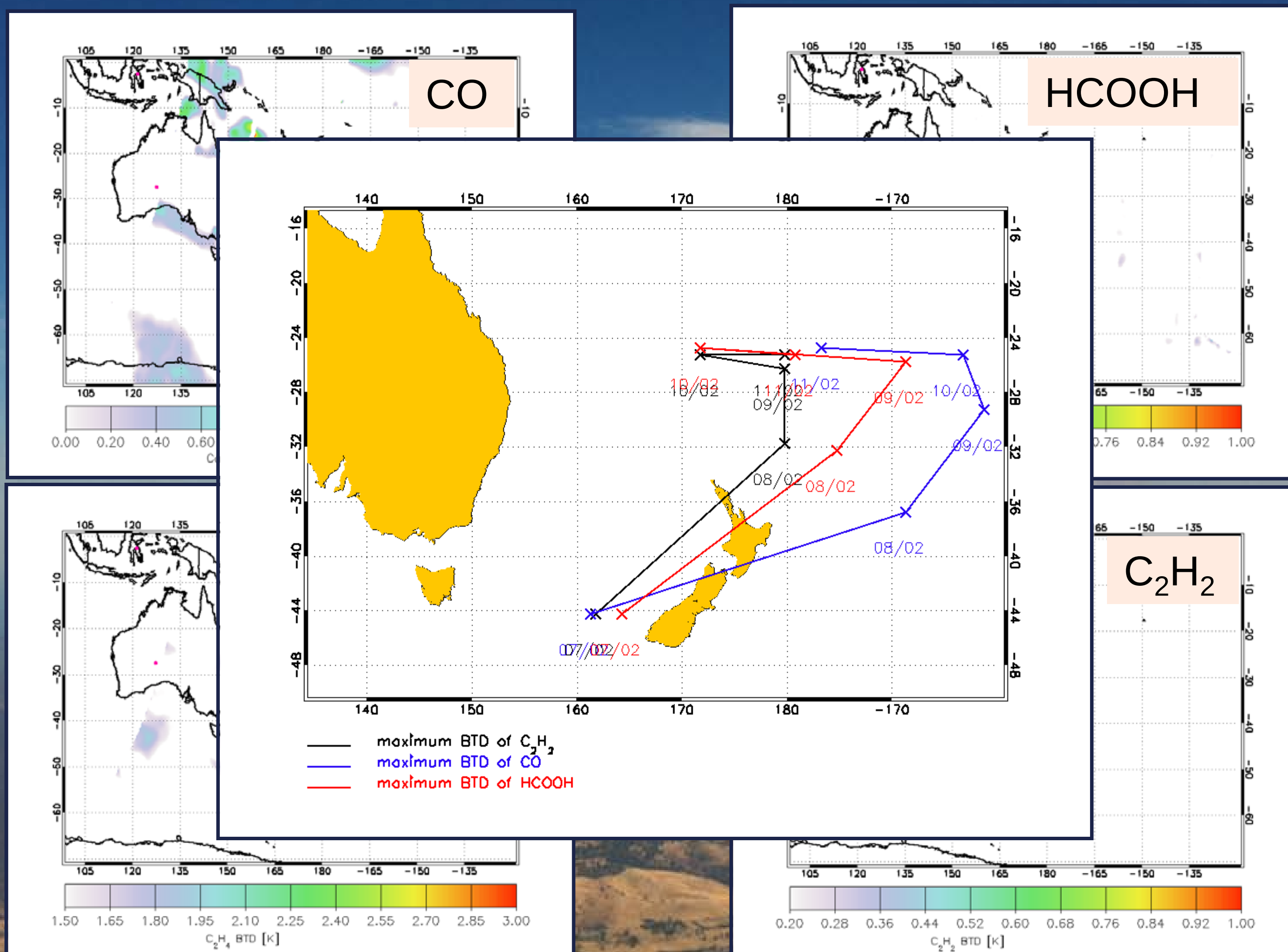
Following plume tracks with IASI



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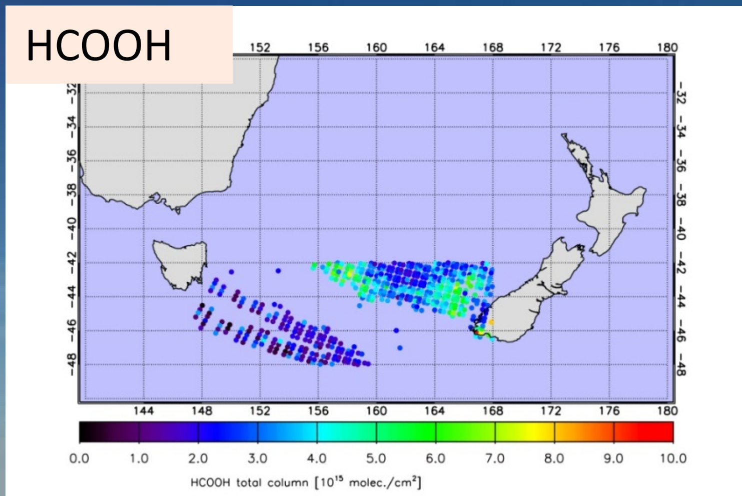
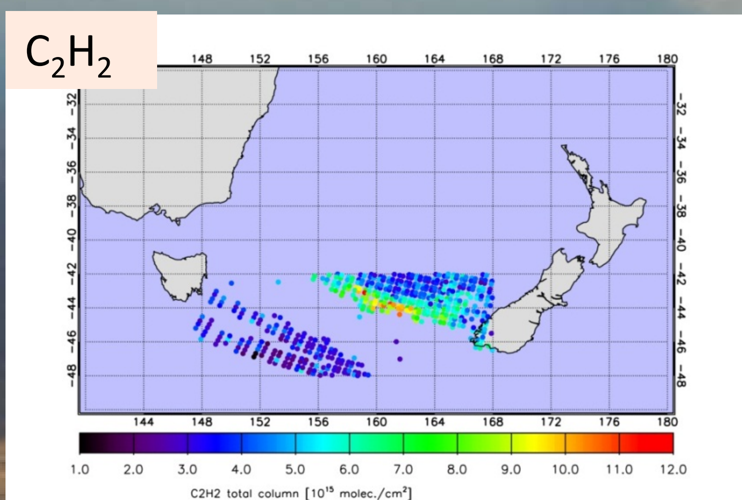
HCOOH and C_2H_2 retrievals

HCOOH



1000%

C_2H_2



1000%

- Test region during Black Saturday where detection suggests high HCOOH and C_2H_2
  - Compare effects of varying a priori covariance
  - Model variability (and vmr) assumed too low
- Effect of varying a priori variability:
  - More sensitivity to HCOOH and C_2H_2 in areas where detection approach indicates enhanced gas concentrations
  - Total column amount allowed to vary
- Apply this approach to data from BORTAS campaign
  - A priori from TOMCAT model
  - 1000 % a priori variability

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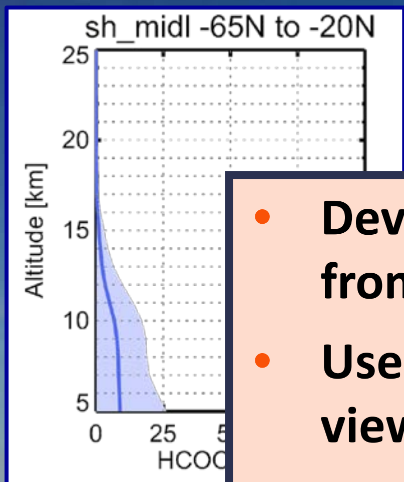
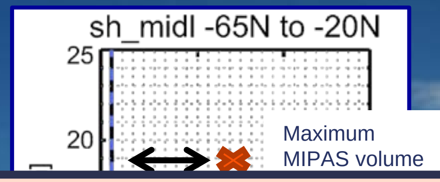
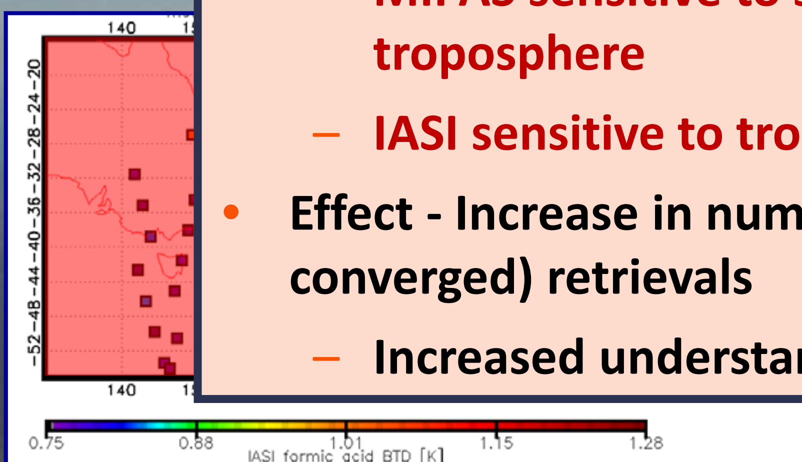
Formic Acid retrievals





- Choosing a priori profile (+shape) essential
- TOMCAT model data used as first … rage”
- … n HCOOH … ere and
- … cm^{-1} for
- … rature … tant … d … m^{-1}

- **Develop IASI full physics retrieval scheme for gases from biomass**
- **Use complementary nadir (IASI) and limb (MIPAS) views to aid IASI total column retrievals.**
  - **MIPAS sensitive to stratosphere and upper troposphere**
  - **IASI sensitive to troposphere**
- **Effect - Increase in number of “successful” (i.e. converged) retrievals**
  - **Increased understanding of particular events**



Retrieved HCOOH from MIPAS at 18 km (squares) overlain with IASI HCOOH detection (circles)

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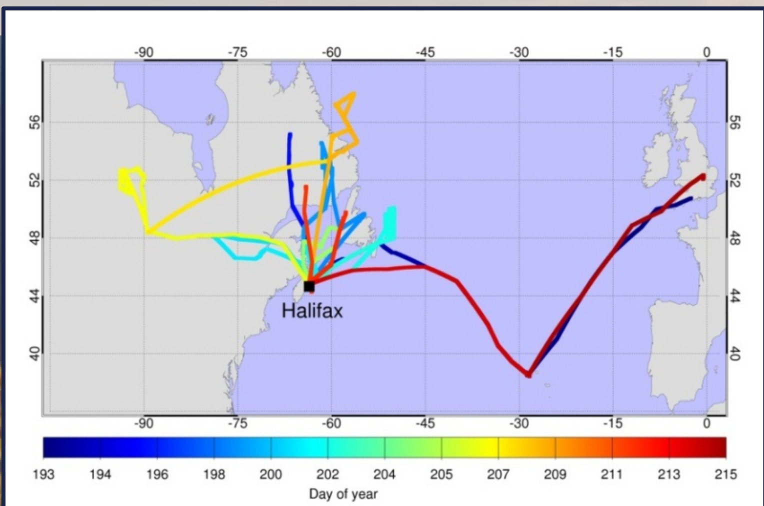
BORTAS (Quantifying the impact of BOReal forest fires on Tropospheric oxidants over the Atlantic using Aircraft and Satellites)

- **Five science objectives:**
  - sample biomass burning outflow from boreal North America over the western boundary of the North Atlantic during summer 2011 using the FAAM146 aircraft;
  - describe observed chemistry within plumes by using the measurements to constrain the Master Chemical mechanism (MCM), with particular attention to the NO_y and organic chemistry;
  - derive a reduced chemical mechanism suitable for a global Chemical Transport Model (CTM) that accurately describes chemistry within the plumes;
  - quantify the impact of boreal forest fires on oxidant chemistry over the temperate and subtropical Atlantic using a nested 3-D chemistry transport model, driven by a subset of MCM chemistry and by assimilated field measurements; and
  - **detect, validate and quantify the impact of boreal biomass burning on global tropospheric composition using data from space-borne sensors.**

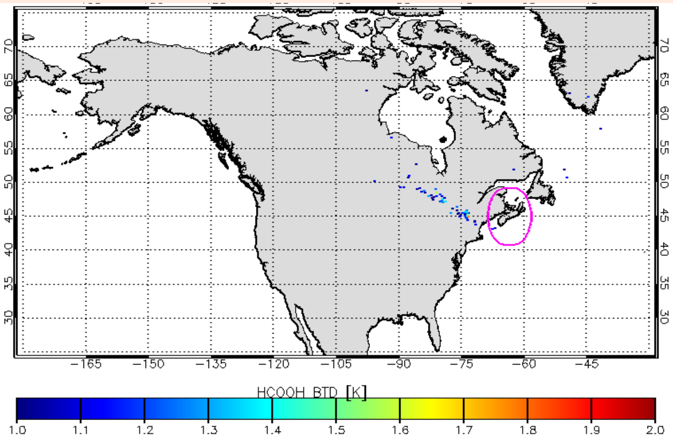


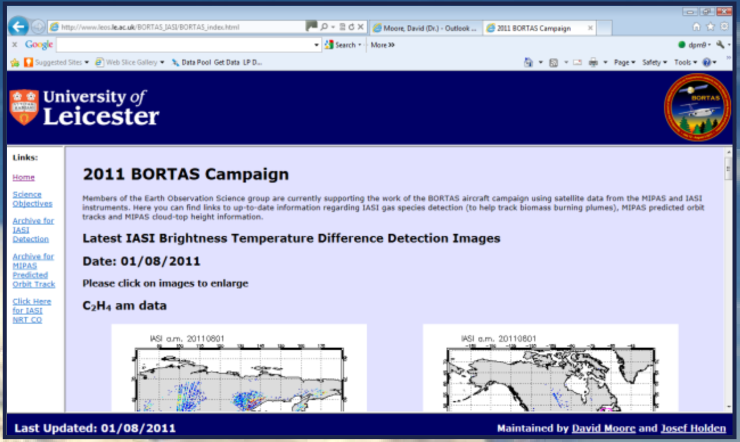
Leicester inputs:

- **MIPAS – PAN, acetone, C_2H_2, HCOOH, (HCN)**
- **IASI - HCOOH, C_2H_4, C_2H_2 (all detection) and CO (total column retrieval and quick detection) for IASI**

IASI "near-real-time" website

HCOOH BTD detection – July 19th 2011

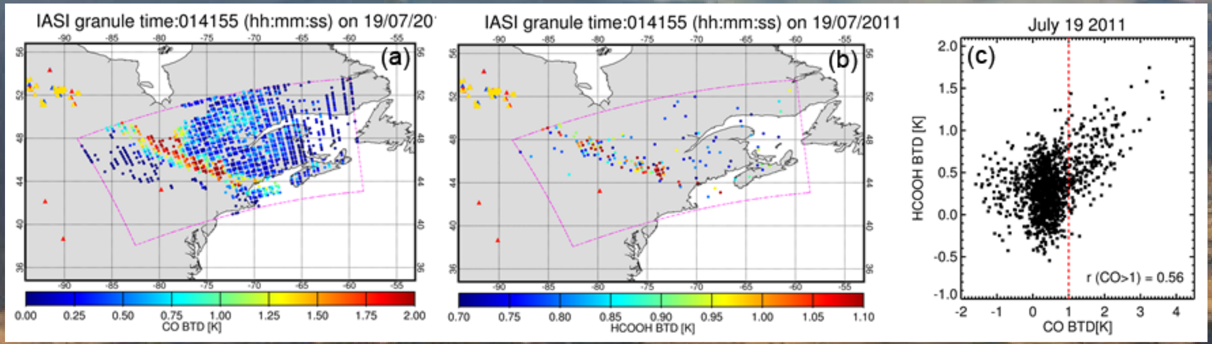




- Developed in support of BORTAS campaign
- Found at **http://www.leos.le.ac.uk/BORTAS_IASI/BORTAS_index.html**
- Show CO, C_2H_2, C_2H_4, HCOOH, HCN for day/night
  - Includes MODIS fire counts
- Developments ongoing + archiving of data/images

CO BTD detection – July 19th 2011

HCOOH BTD detection– July 19th 2011 (zoomed)



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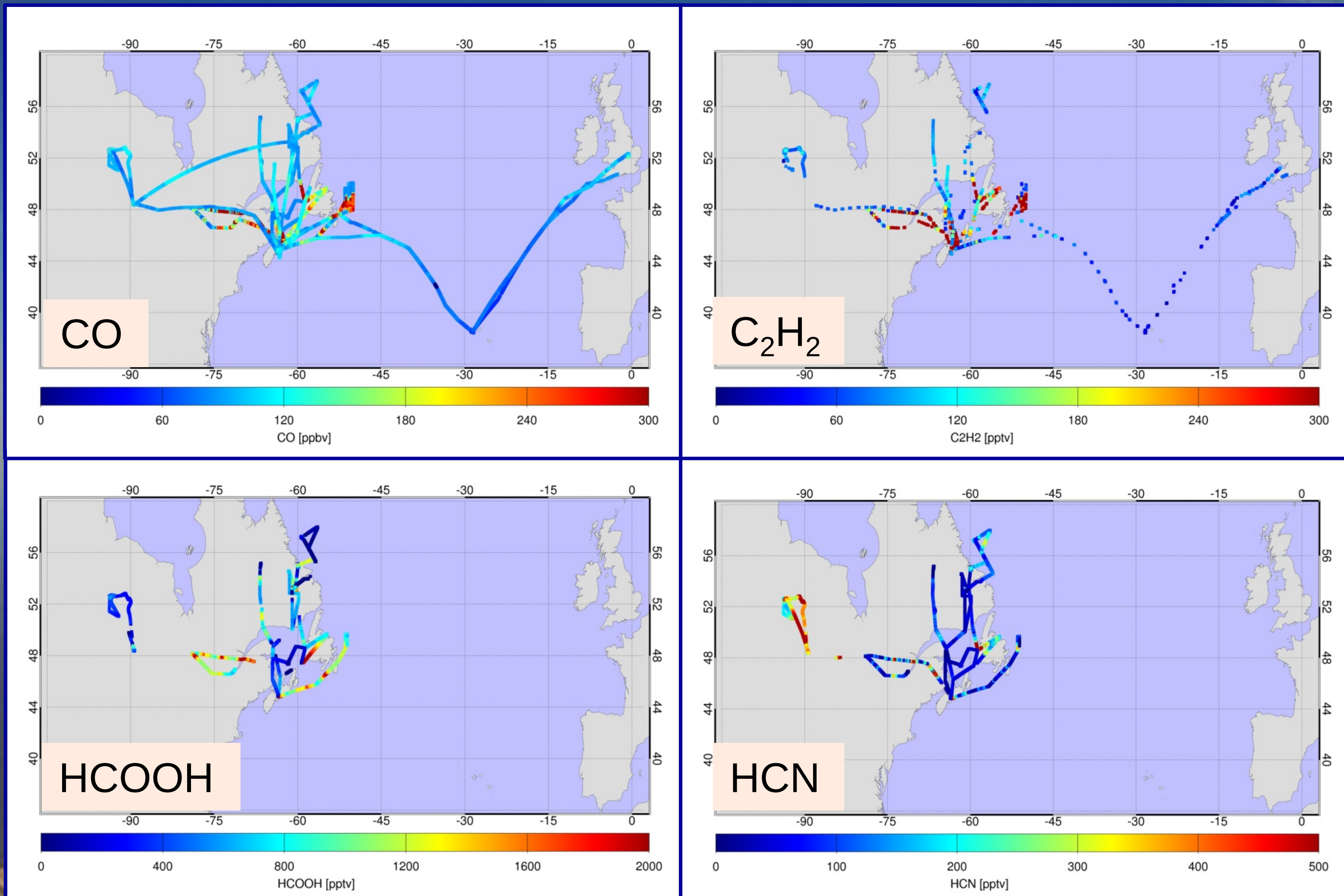
Along-track measurements during during BORTAS



- All flights during July 12th- August 3rd period

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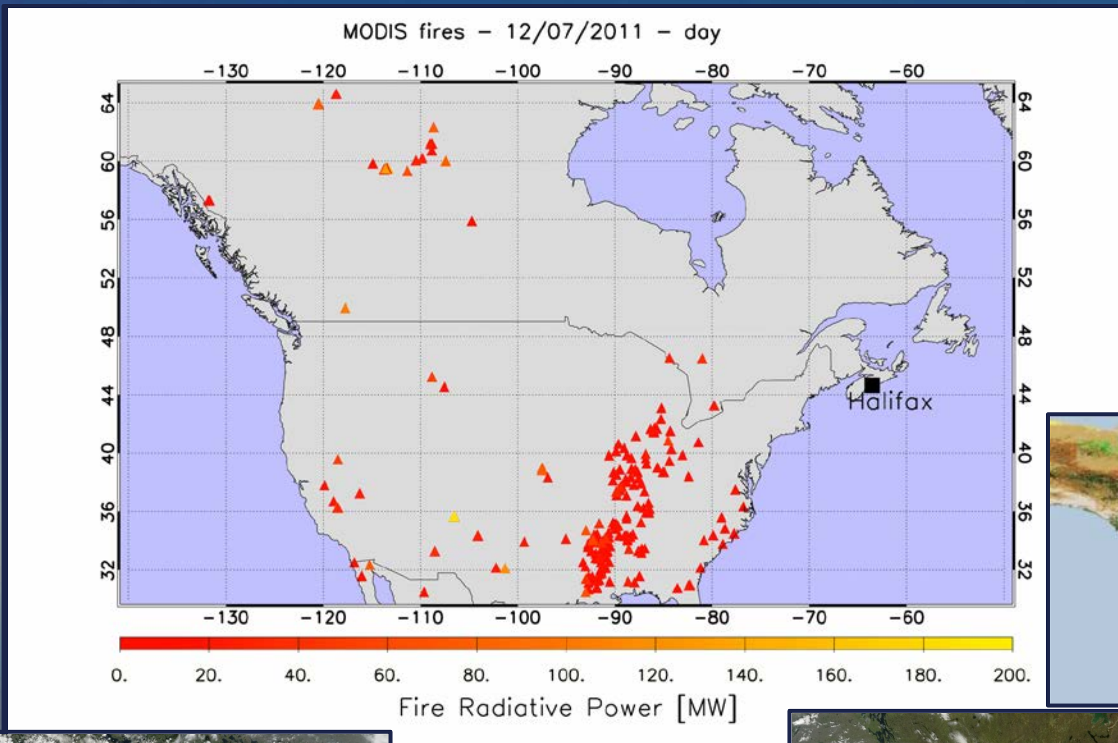
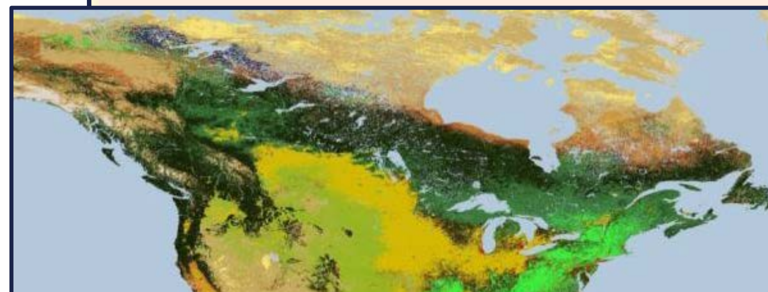
Fire activity during BORTAS



- Moderate fire activity over boreal forests of Canada
  - Most activity during 14-20th July over North-west Ontario (central Canada)
  - Fires later in the month over Northwestern Territories and Nunavut Territory



Above: MODIS land classification – dark greens represent regions of Evergreen needle forest

Left: Wildfires near McLeod Bay created thick smoke observed by MODIS on July 23. Over the next couple days, winds carried the smoke hundreds of kilometers eastward. In this image, smoke forms a serpentine pattern across Nunavut and Hudson Bay. *Image courtesy of NASA Earth Observatory*

Left: Smoke from wildfires blew across Canada's Northwestern Territories and Nunavut Territory in late July 2011. The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite captured this natural-colour image on July 25, 2011. *Image courtesy of NASA Earth Observatory.*

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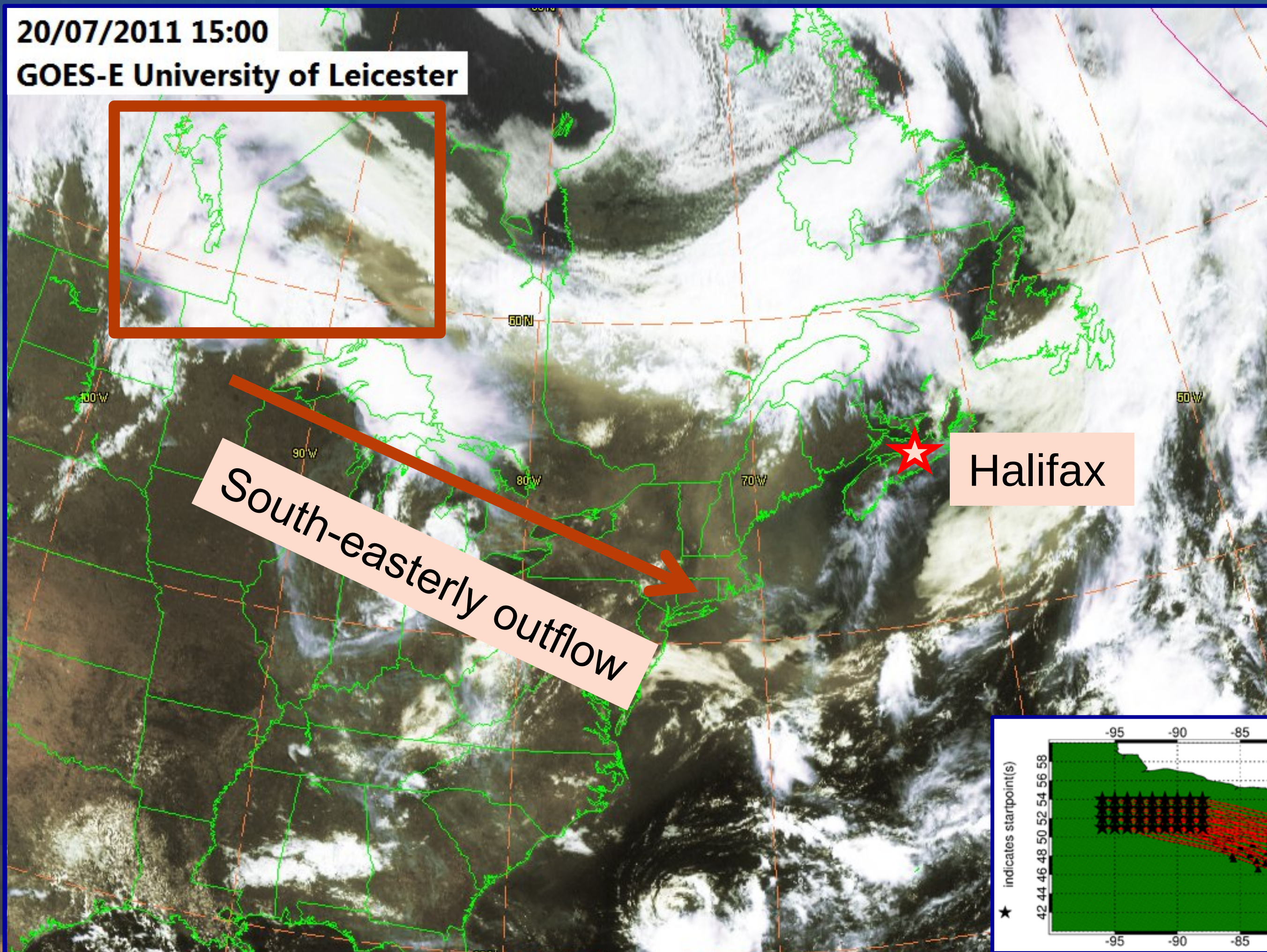
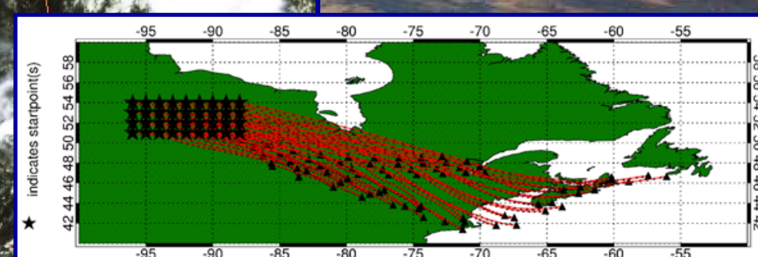
Geostationary satellite imagery of the NW Ontario fires



- Images taken from Goes-E satellite
- False colour visible images

- Closest daily observation to daytime IASI overpass

- **Main transport pathway to south-east** – towards measurement area of BORTAS aircraft



Hysplit trajectory (4 km level), initiated 12z 17/07/2011

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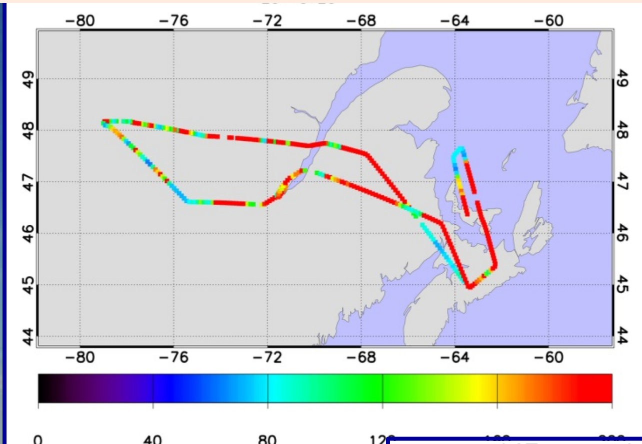
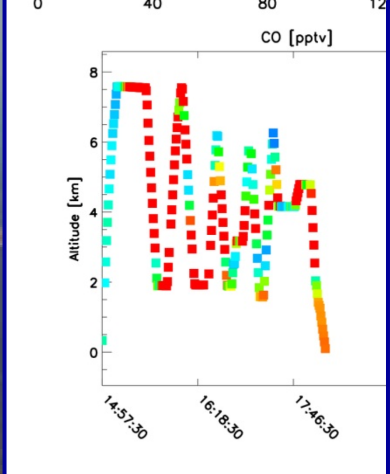
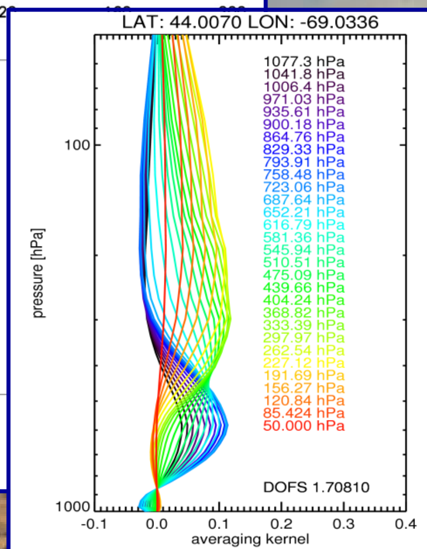
IASI CO validation – July 20th

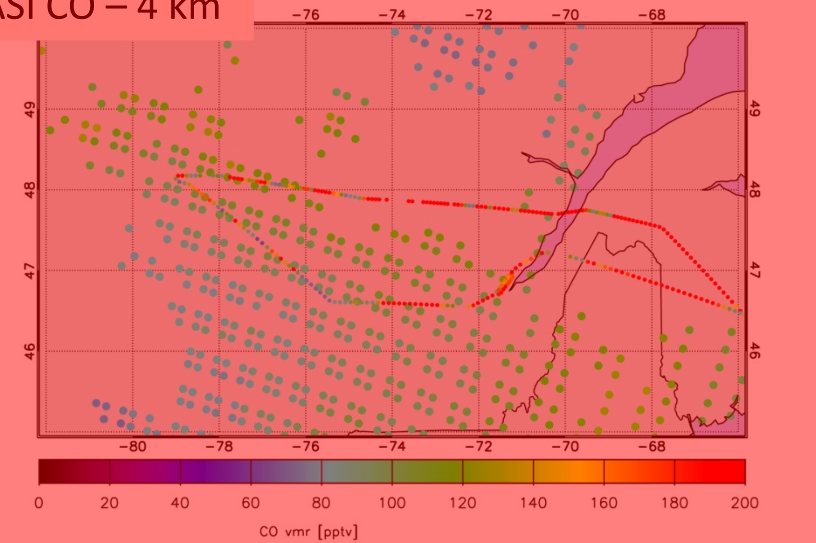
CO – flight B622 – July 20th 2011







IASI CO – 4 km



Above: along-track CO measurements from flight B622 on July 20th 2011 over the Quebec region of Canada, overlain on IASI CO (daytime) from 20th.

- Significant CO enhancement measured during this flight
- IASI most sensitive to CO at 600 hPa (4 km) and 300 hPa (10 km)
- IASI CO vmrs at 4 km level compare well with BORTAS measurements

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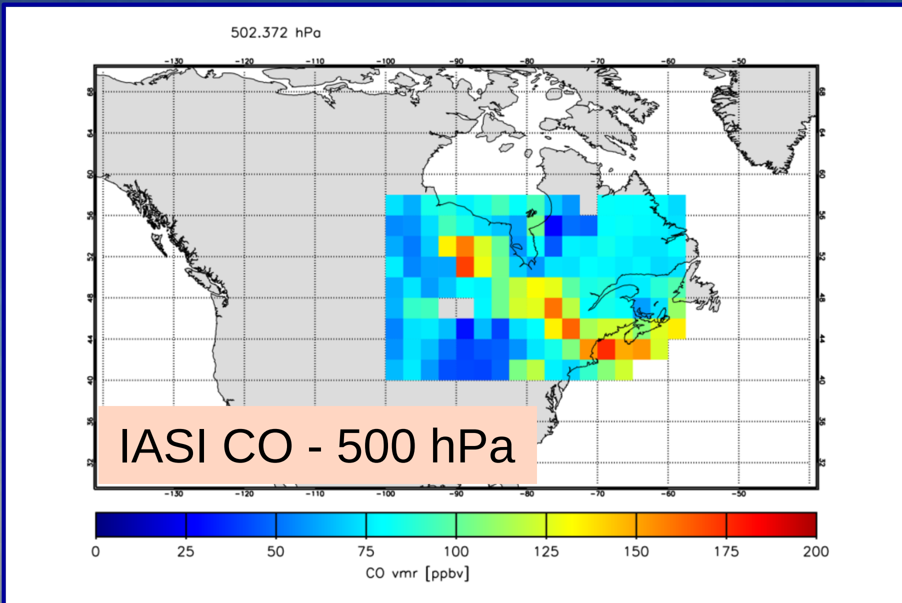
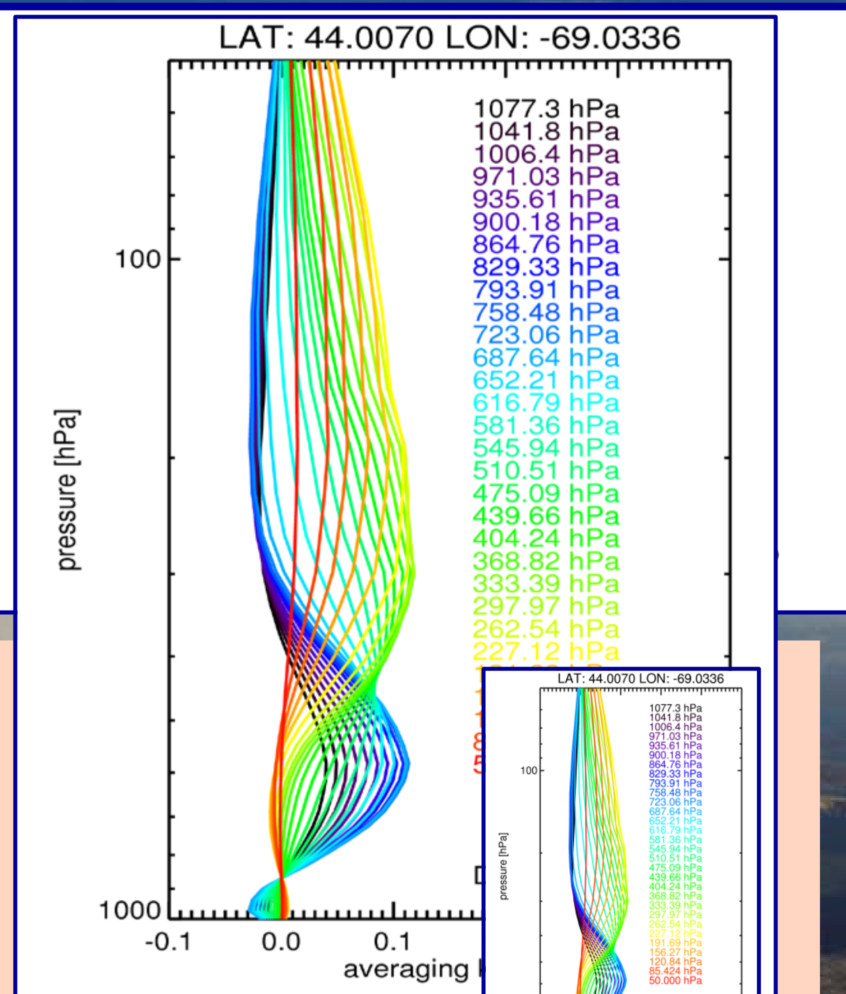
Carbon Monoxide – model comparisons





- Clear plume event measured by IASI on 19/07/2011 from NW Ontario fires
- IASI sensitive to Carbon Monoxide in mid-troposphere
- Plume not observed in GOES-CHEM at closest level
- Application of IASI Averaging kernels to GEOS-CHEM, has small effect, apart from close to emission region

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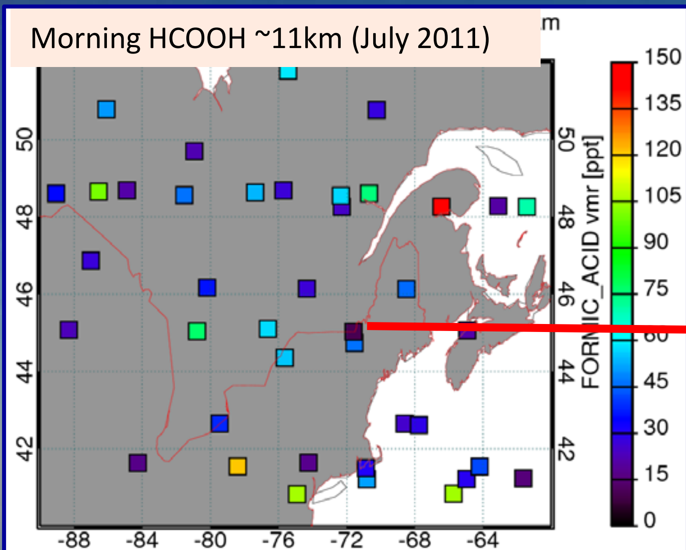
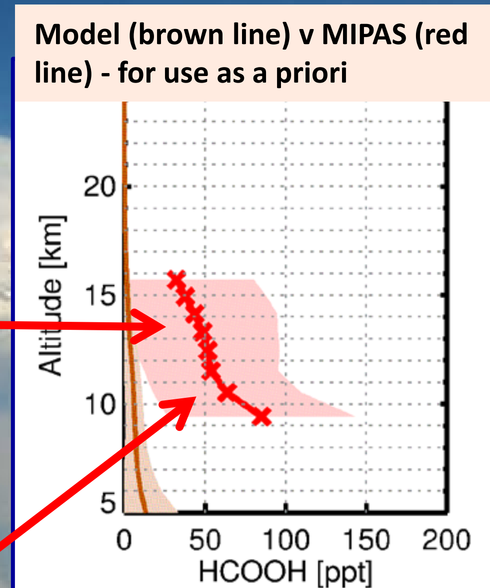
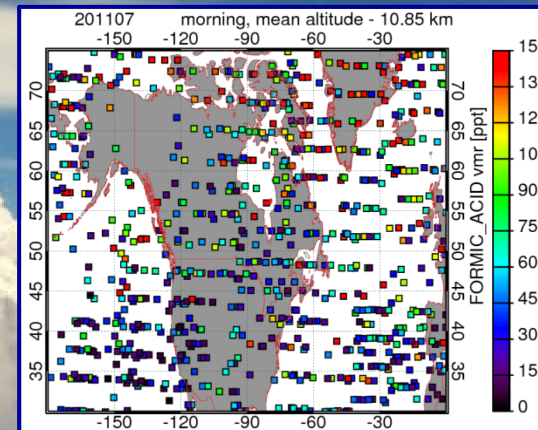
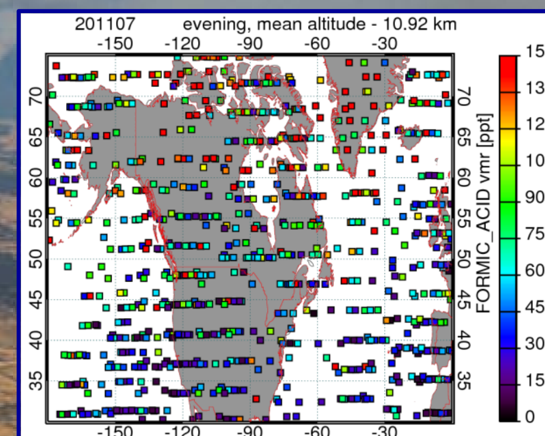
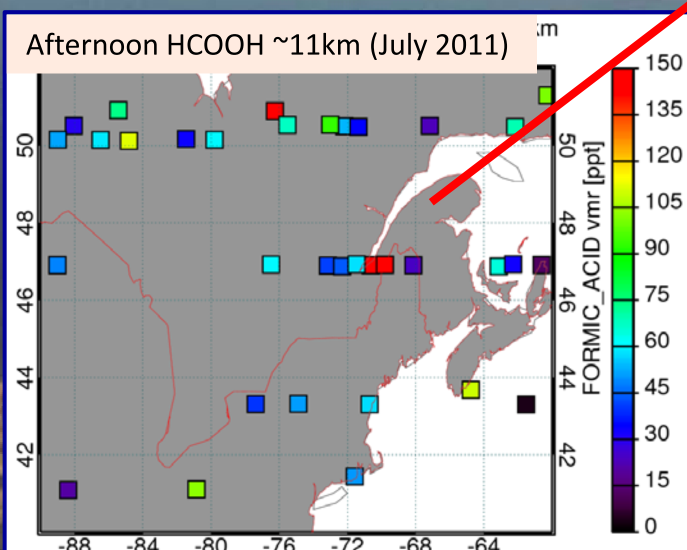
MIPAS HCOOH observations in July 2011











- High variability of HCOOH in upper troposphere observed by MIPAS over month
- Average MIPAS (red) profile x5 to x8 higher in MIPAS observations compared to model (brown)

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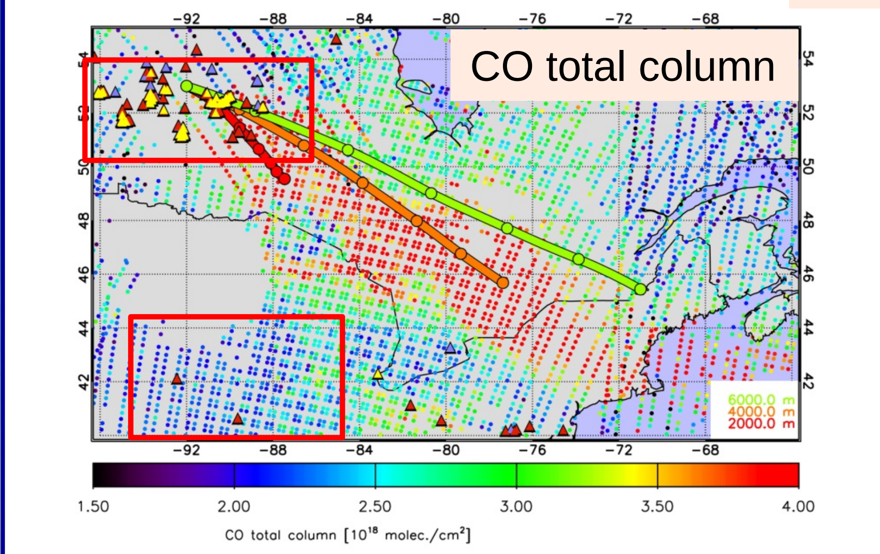
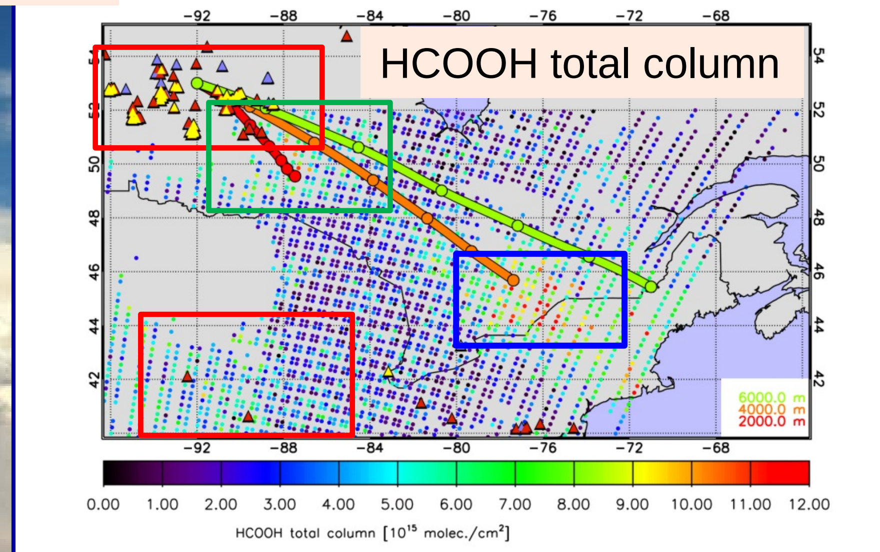
Enhancement ratios of HCOOH

July 19th





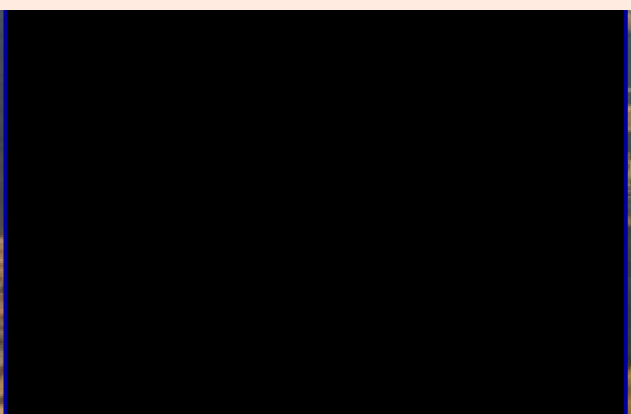
$\Delta HCOOH/\Delta CO$

Blue Square : 0.021±0.0099

Green square: 0.0038±0.0021

$$\frac{\Delta HCOOH}{\Delta CO} = \frac{[HCOOH]_{plume} - [HCOOH]_{background}}{[CO]_{plume} - [CO]_{background}}$$

MODIS fire power over NW Ontario

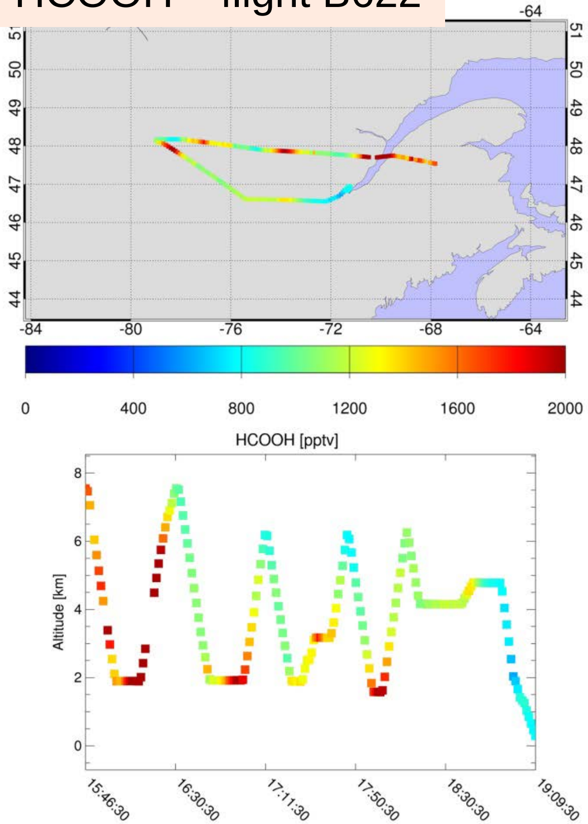


Compare to results from Goode et al., 2000:

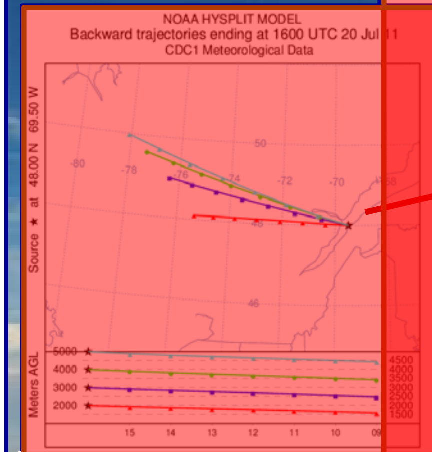
- Measurements from Alaskan biomass burning plumes taken with airborne FTIR
- **Alaskan Enhancement ratios in range 0.0052-0.0158**
- Seeing **higher ratios** from Ontario fires
  - Time for secondary production to occur
  - Also an order or magnitude higher than Akagi et al. (2011)
  - Comparable to enhancements from (mainly) peat fires over Russia in 2010 (Rhoni et al., 2012) – 0.010 to 0.030.

IASI Formic acid – 20/07/2011

HCOOH – flight B622

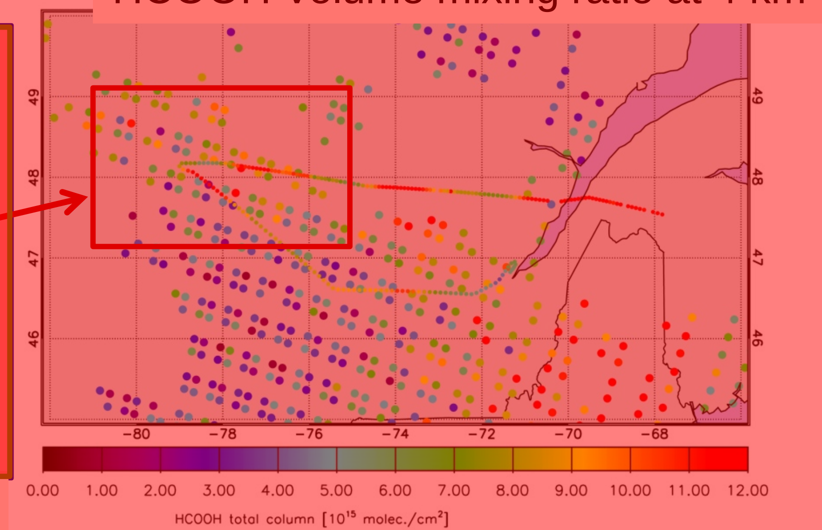


Above: along-track HCOOH measurements from flight B622 on July 20th 2011 over the Quebec region of Canada



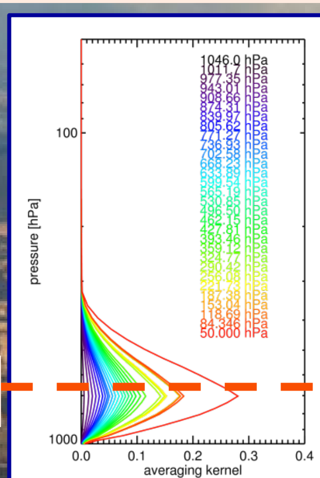
Above: HYSPLIT 7-hour back trajectory from source of highest HCOOH on July 20th

HCOOH Volume mixing ratio at 4 km



Above: along-track HCOOH measurements from flight B622 on July 20th 2011 over the Quebec region of Canada, overlain on IASI HCOOH (daytime) from 20th.

4 km



Above: A Formic acid averaging kernel (enhanced case)

- High HCOOH originates from west of Quebec (Hysplit trajectories)
- IASI HCOOH vmrs at 4 km compare well with BORTAS measurements
  - Much higher than 100 pptv *a priori* value at this level
  - Possible enhancement of HCOOH between IASI measurement and aircraft?
- IASI most sensitive to HCOOH in mid-troposphere (~4 km)

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Summary

- **Disruptive events emit large amounts of short-lived species** with lifetimes of up to a few months into the Earth's atmosphere affecting chemistry, convection and emissions and, indirectly, its climate response
- NCEO funding has allowed us to **respond to support campaigns**, such as the NERC funded BORTAS, and unexpected events such as **wildfires**.
- Volatile Organic Compounds (VOCs) are clearly **important for tracing biomass emissions**, for **understanding troposphere chemistry** control (and hence future climate-chemistry feedbacks), and for **pollution transport**.
  - Total and partial column retrievals of IASI (ULIRS) CO, HCOOH and C_2H_2 and MIPAS (MORSE) PAN data aiding understanding of plume chemistry from boreal fires in conjunction with in-situ data
  - Results show **HCOOH plume enhancements** captured by in-situ measurements represented well in ULIRS partial column data and confirmation with HYSPLIT model
  - Evidence of **secondary production of HCOOH in biomass plume from boreal fires.**
    - **Enhancement ratios of 0.021 ± 0.0099**
- The retrievals are complicated mathematical processes and are sensitive to information constraints which need to be understood and compared carefully.

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Acknowledgements

- National Centre for Earth Observation for funding
- European Space Agency (for provision of MIPAS data)
- Eumetsat (for provision of IASI data)
- BORTAS team
- Anu Dudhia – MIPAS retrieval scheme (MORSE), and forward model (RFM)

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EXTRA SLIDES

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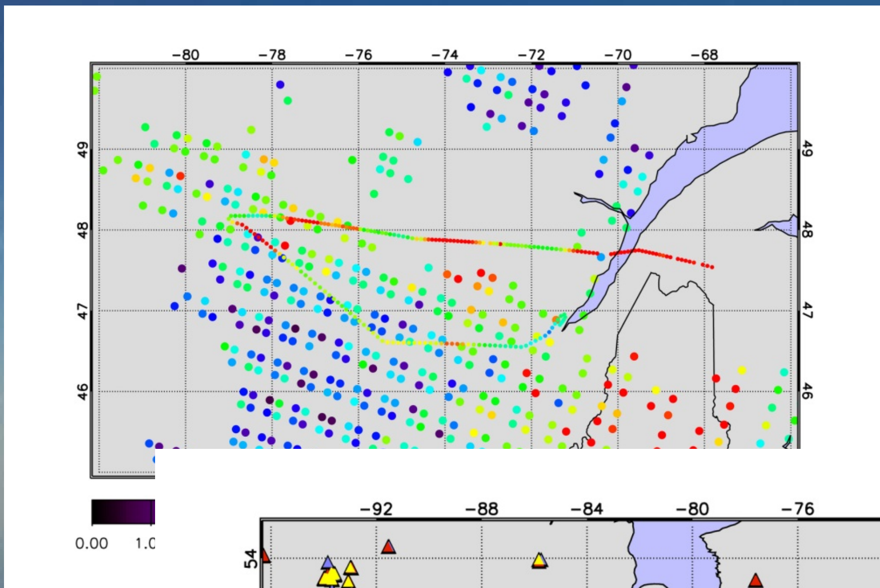

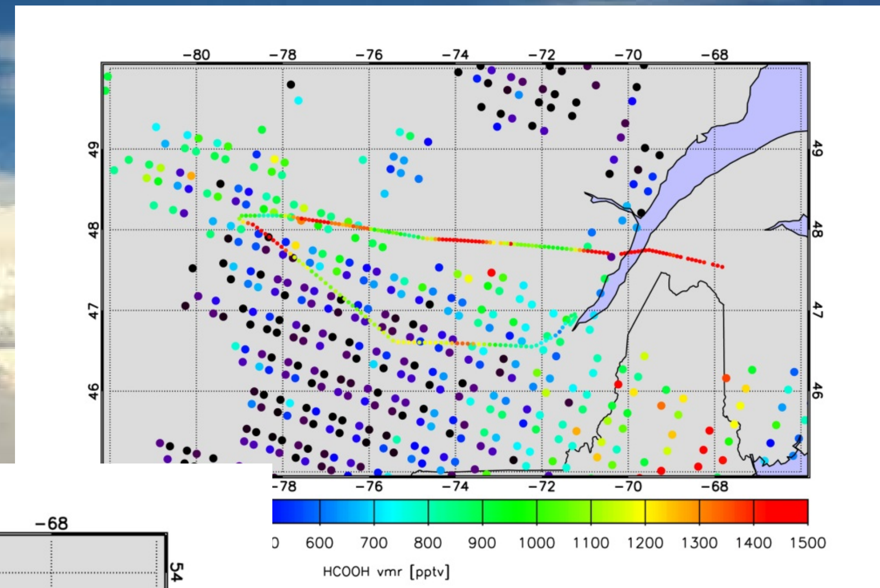

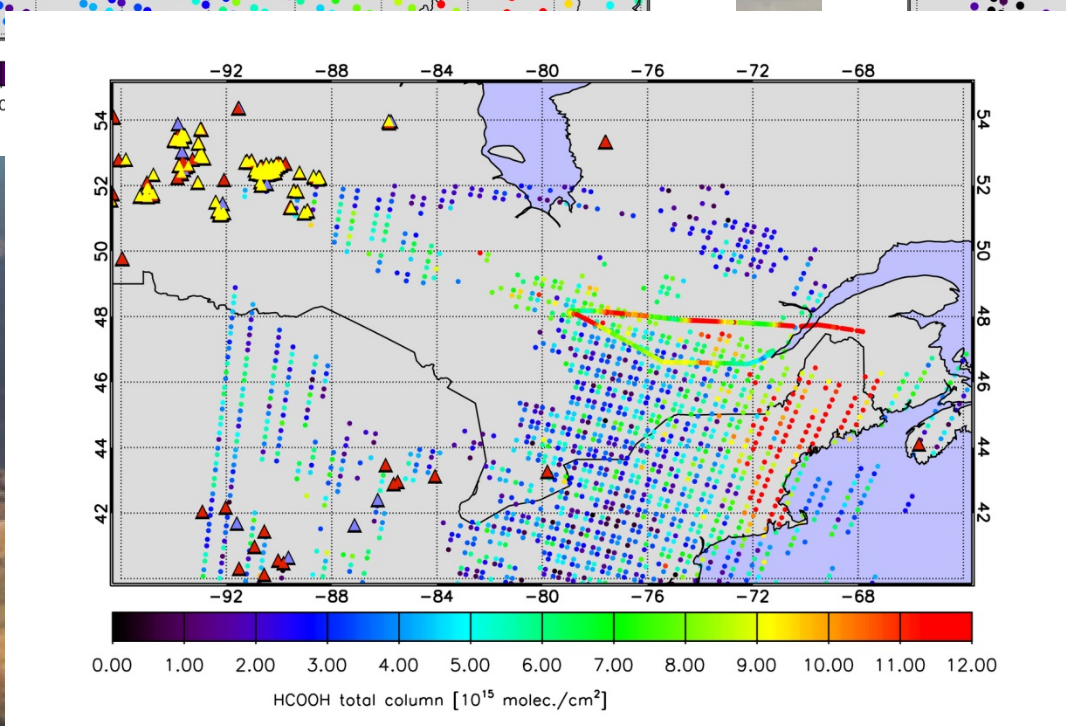

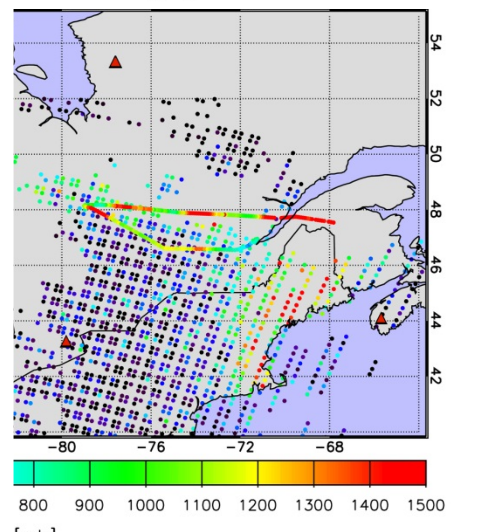

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EARCH COUNCIL

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Summary

- Overview of species we detect with IASI (and MIPAS)
  - Demonstration of quick detection approach for "Black Saturday" event over Australia (Feb.2009): CO, HCOOH, C_2H_2, C_2H_4
  - Diverging trajectories of maximum brightness temperature differences show IASI is suitable to determine plume chemistry
    - being used to test chemical transport models

- Presented description of ULIRS scheme to retrieve CO, HCOOH and C_2H_2
  - For more information on scheme refer to Illingworth et al., AMT, 2011.
  - Important effects of a priori covariance variation
  - **Use MIPAS measurements to better represent stratosphere in a priori data**

- Application of ULIRS retrievals to BORTAS campaign (Jul. 12th-Aug. 3rd 2011)
  - Leicester near-real time website shows up to date daily global images of gas detections (via Eumetcast data dissemination)
  - Total and partial column retrievals of ULIRS CO, HCOOH and C_2H_2 data aiding understanding of plume chemistry from boreal fires in conjunction with in-situ data
  - Initial results show HCOOH plume enhancements captured by in-situ measurements represented well in ULIRS partial column data and confirmation with HYSPLIT model

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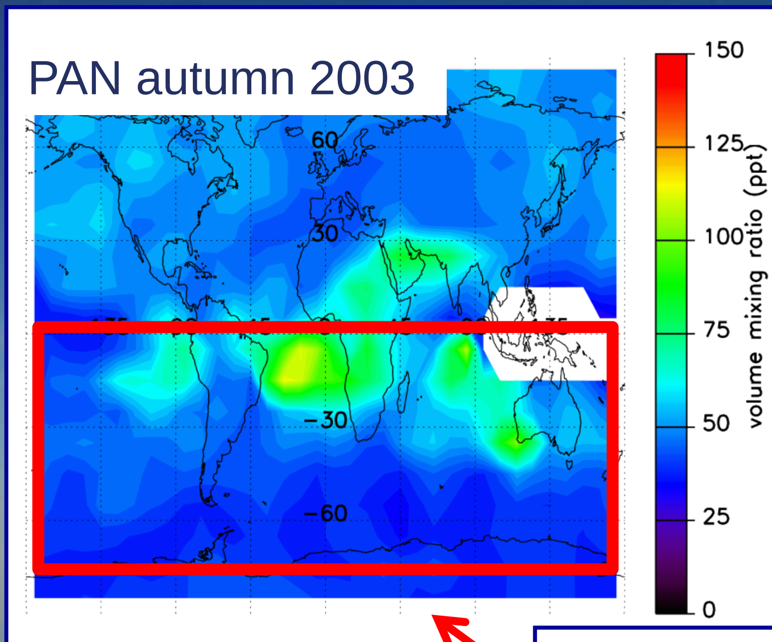
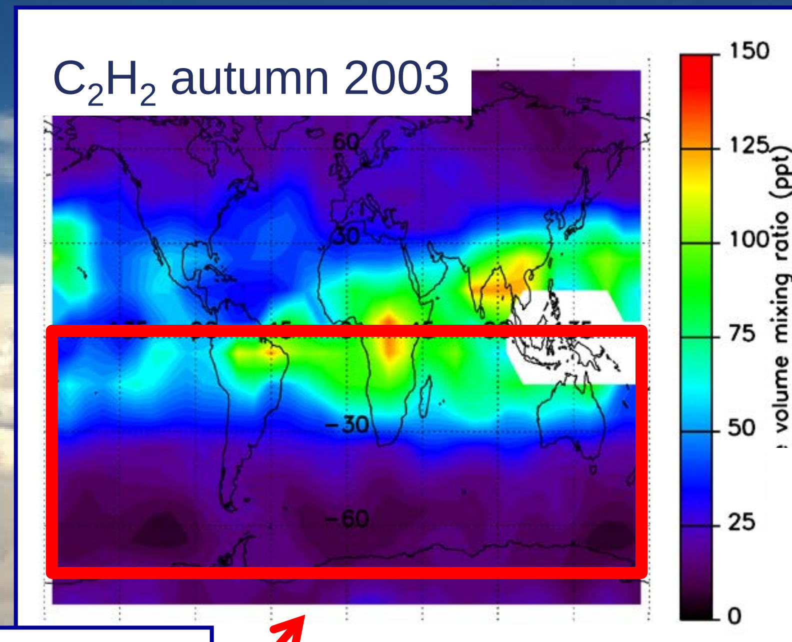
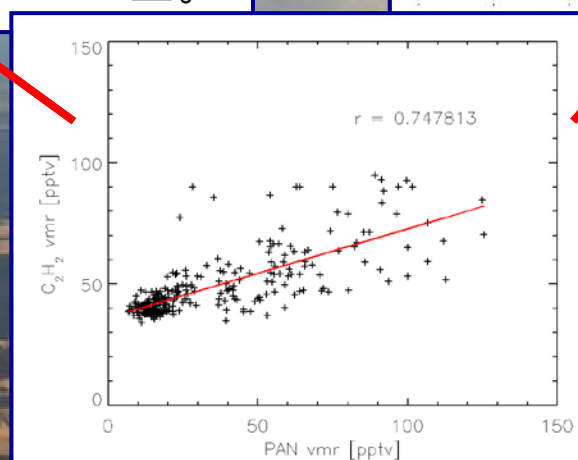
PAN from biomass burning







- C_2H_2 a good marker of biomass burning
  - Probably largest source in tropics
  - High correlation with PAN in Southern Hemisphere

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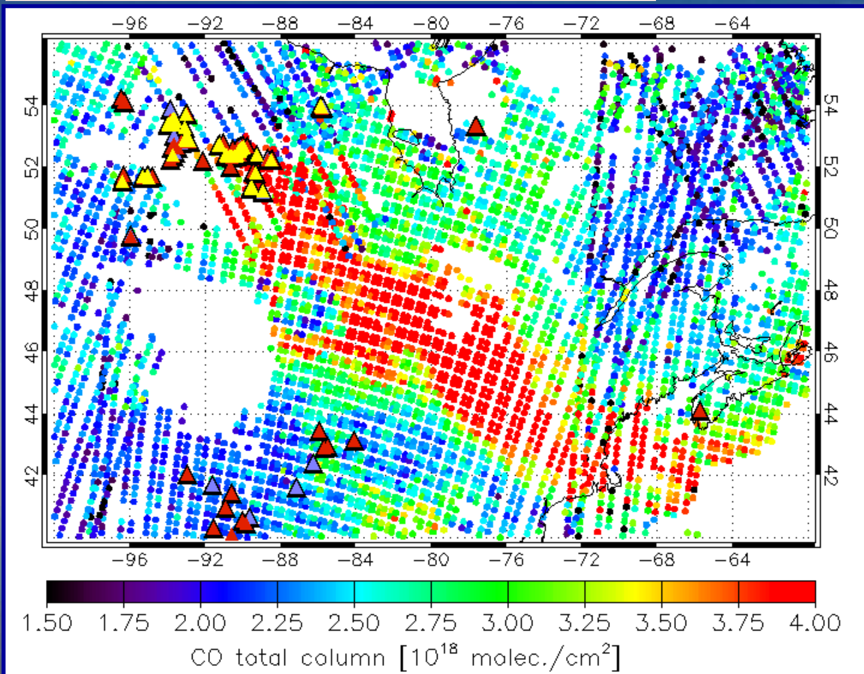
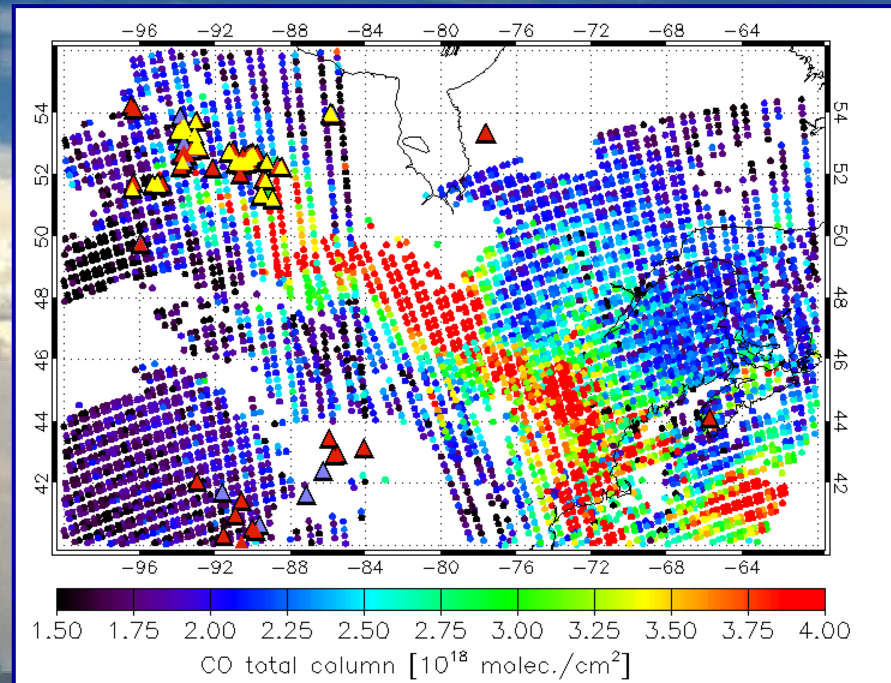
Day/Night differences – 19/07/2011

Carbon monoxide **daytime**



Carbon monoxide **nighttime**



- Daytime CO
  - Same plume feature but:
    - Higher concentrations or
    - Higher surface thermal contrast -> higher sensitivity to CO near surface
  - Test with GEOS-CHEM (+ averaging kernels)

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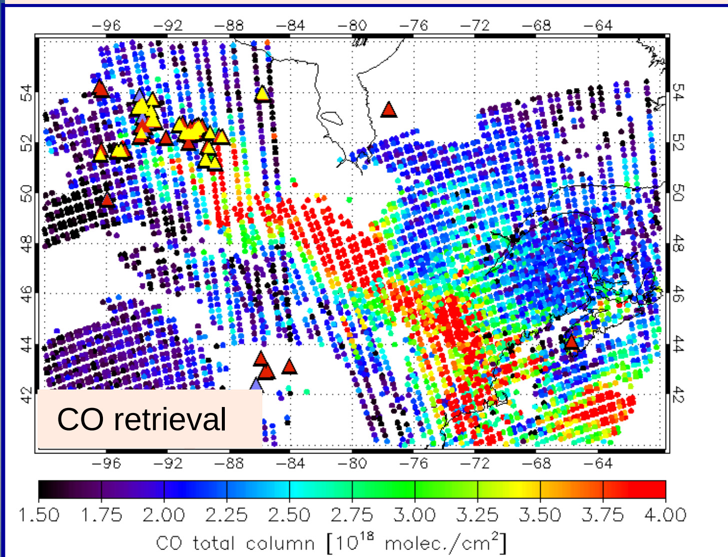
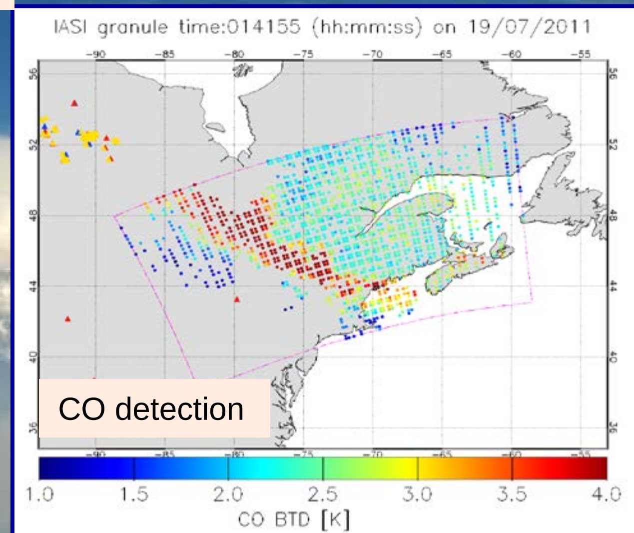
Biomass burning plume - 19th July

University of Leicester

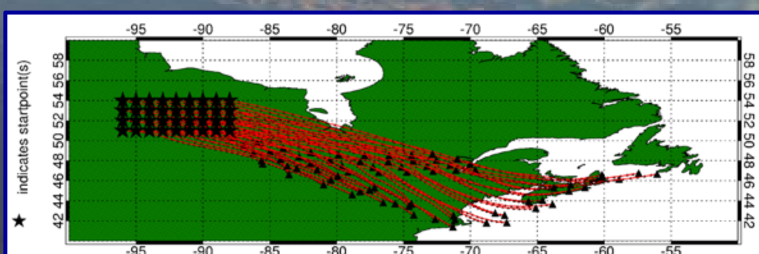
Full carbon monoxide retrieval – night-time



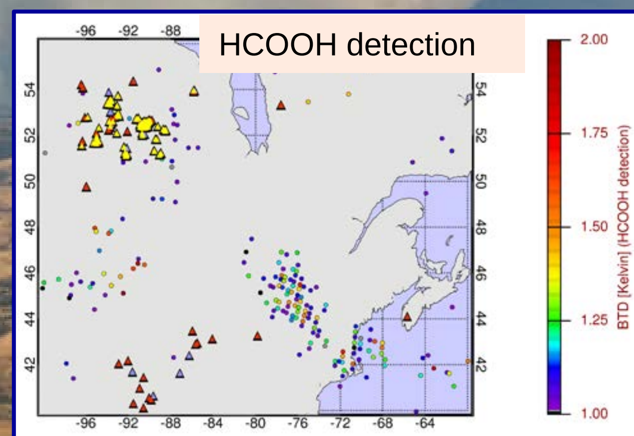
CO detection (near-real time)



- Verification of Leicester "quick detection" approach – differencing of IASI brightness temperatures over suitable channels
- HCOOH detection in plume
- Averaging kernels available for each retrieval



Above: Hysplit trajectory (2 km level), initiated 12z 17/07/2011



Left: HCOOH detection on July 19th 2011 from NW Ontario fires.

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