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Canadian TEMPO-related Activities

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Air Quality Research Division, Environment Canada

3rd TEMPO Science Team Meeting

Huntsville, AL • 27-28 May 2015

Themes

- Chemical Data Assimilation
- Strat-trop seperation
- Retrievals over snow, identifying presence of snow
  - IMS (Interactive multisensor snow&ice) - NOAA/NESDIS)
  - CaLDAS (Cdn Land Data Assimilation System – EC) – provides snow depth → age of snow
- Emissions
- Validation

Research Activities – CDA

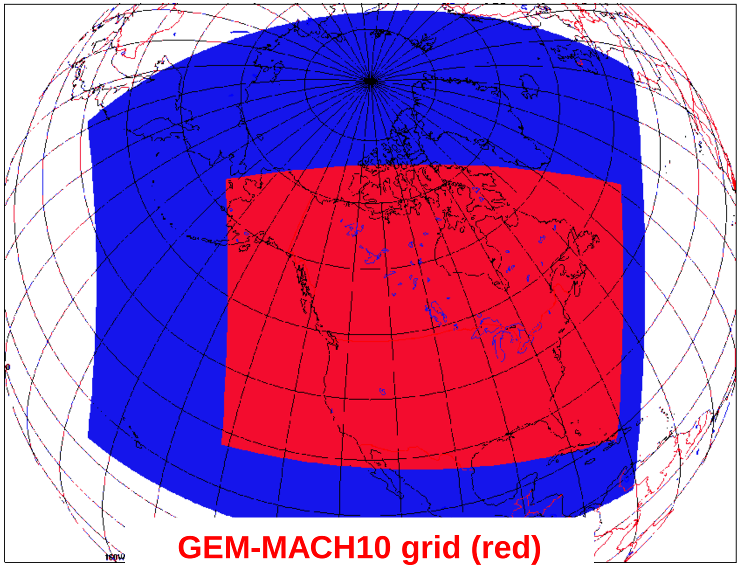
- Currently EC has operational objective analyses of surface O_3, NO_2, SO_2, $PM_{2.5}$, PM_{10} over North America
  - Assimilation of these surface obs is being done in research mode
  - TropOMI, MODIS AOD will be assimilated

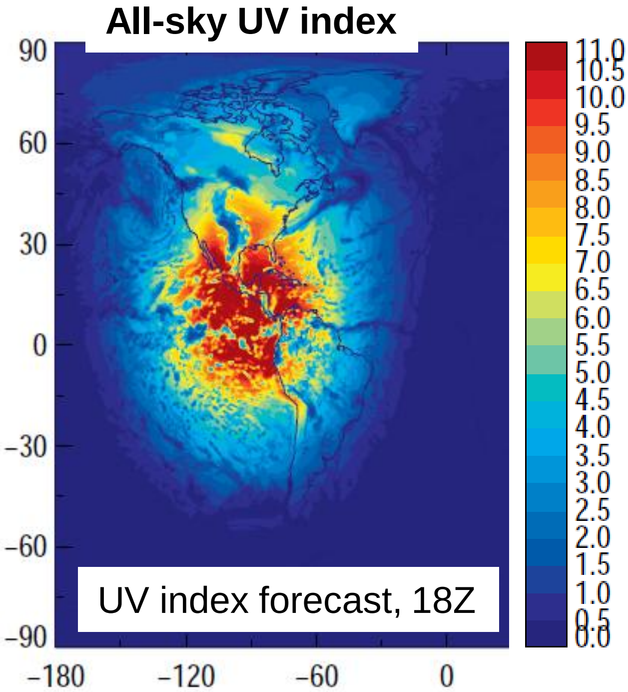
- A large initiative is underway to have an operational assimilation/ forecasting system in place for 2019 that will use:
  - EC GEM-MACH* operational AQ forecast model
  - North American surface stations (O_3, NO_2, $PM_{2.5}$)
  - TEMPO (+ TropOMI) measurements of O_3, NO_2, AOD
  - TEMPO SO_2, HCHO are TBD
  - Stratospheric profiles of NO_2 (pending availability)

* Global Environmental Multi-scale model - Modelling Air quality and CHemistry

Research Activities – CDA

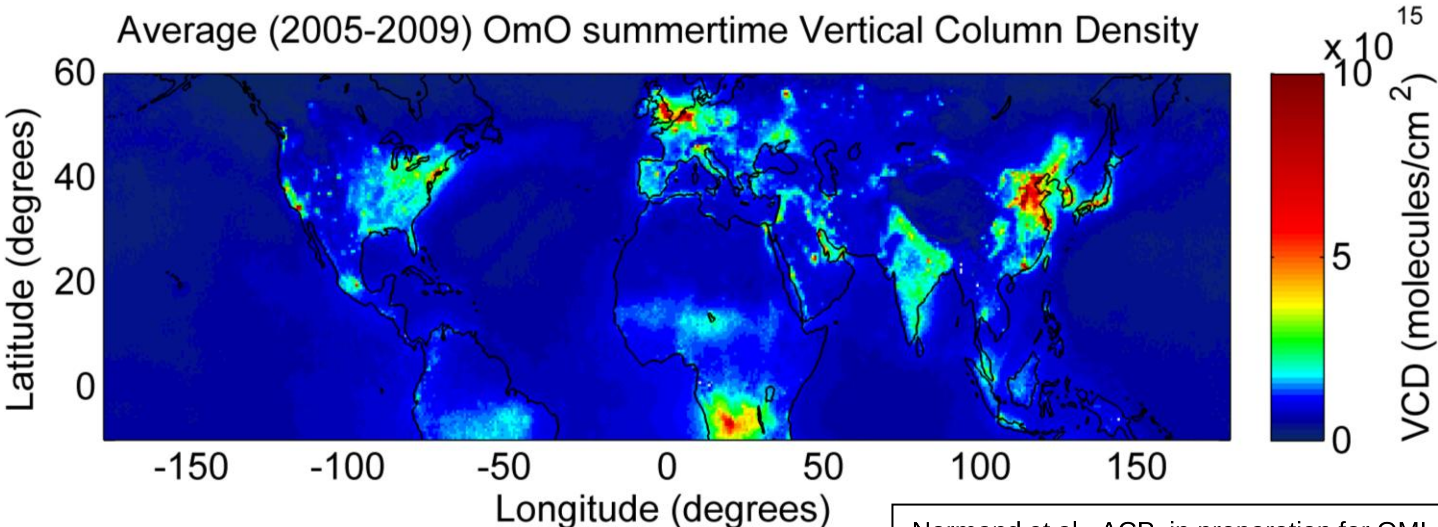
- The system will provide analysis and forecast fields across Canada and CONUS (i.e., the GEM-MACH10 grid):
  - AQ species of interest at surface
  - Stratospheric O_3 and NO_2
  - Surface UV





Research Activities – Limb/Nadir subtraction

- Project between U. Saskatchewan (Adam Bourassa) / U. Toronto (Dylan Jones) / EC
- Question: Can limb-nadir matching be used to isolate trop-NO_2 VCD when measurements are not coincident?
  - Try using OMI and OSIRIS (OMI-minus-OSIRIS) existing level 2 data products
  - OSIRIS NO_2 profile adjusted to OMI LST and integrated through stratosphere
  - 5 years of OMI data re-processed
  - Correction to OMI SCDs provided by Sergey Marchenko



Normand et al., ACP, in preparation for OMI-special issue

Research Activities – Limb/Nadir OSSE

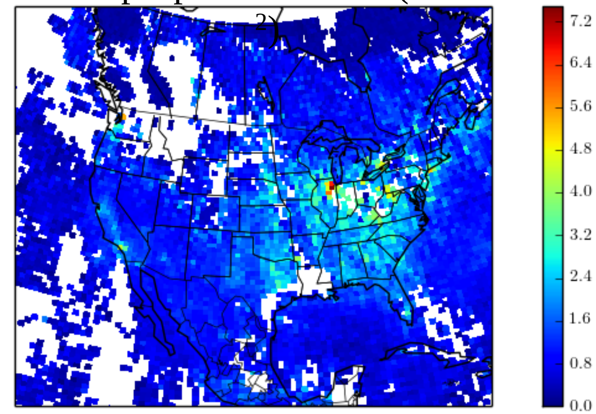
- Project between U. Toronto (Dylan Jones) / Dalhousie (Randall Martin) / U. Sask. (Adam Bourassa) / EC
- Investigate usefulness of NO_2 profiles from proposed limb scatter instrument (CATS = Canadian Atmospheric Tomography System) on TEMPO retrievals using GEOS-Chem:

Trop VCD: High bias in strat NO_2 transferred into tropospheric VCD

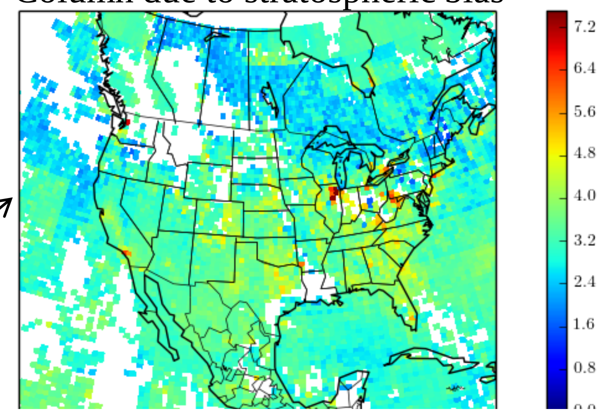
When CATS pseudo-data assimilated

  – Next: Quantify the impact of the stratospheric bias on North American NOx emissions through inverse modeling of pseudo-data from TEMPO and TROPOMI with the nested GEOS-Chem model

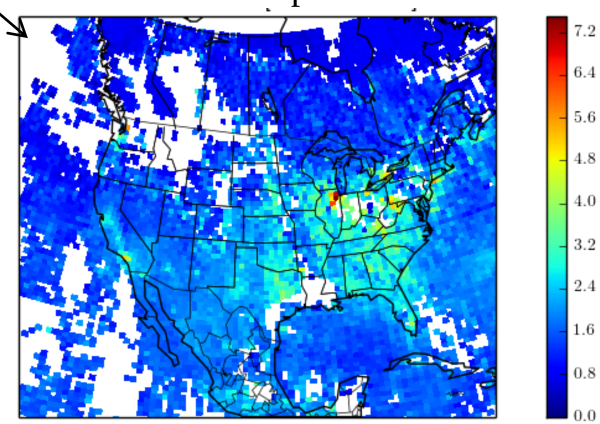
True tropospheric column (10^{15} cm^{-2})



Column due to stratospheric bias



Column after stratospheric assimilation



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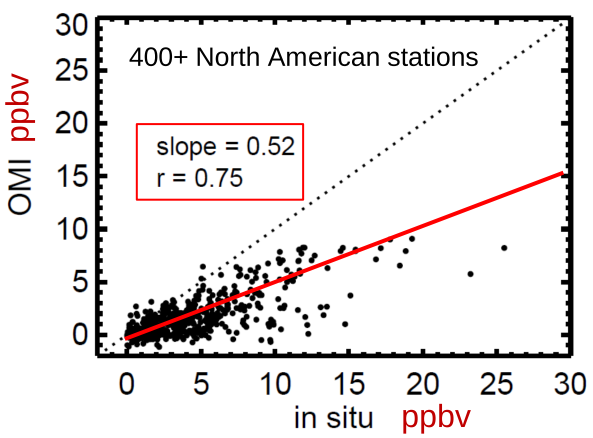
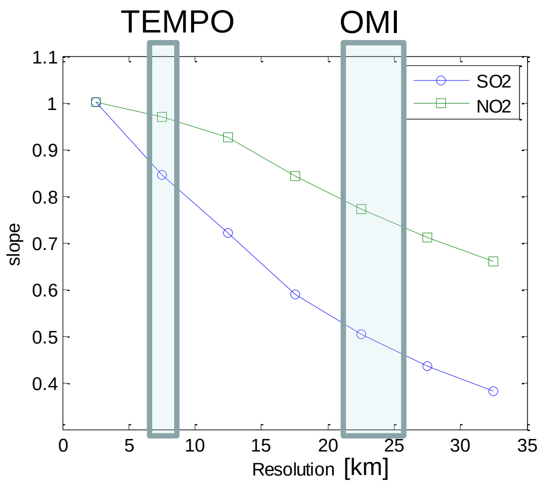
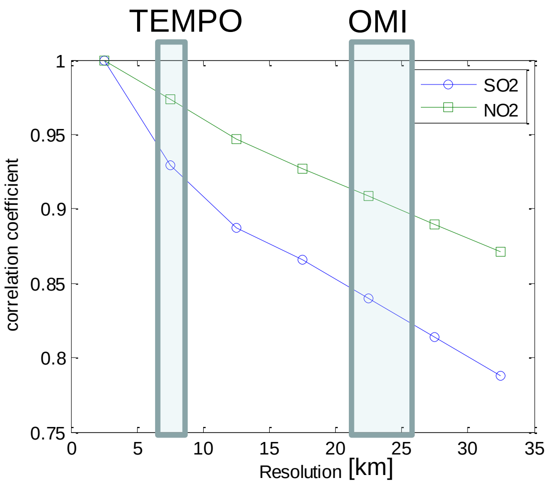
Research Activities – Monitoring and impact of resolution

- 2.5 km version of GEM-MACH used to examine effect of resolution on satellite-surface comparisons
  - Model values smoothed to difference effective resolutions and sampled at location of surface stations
- Value of OMI-surface SO_2 slope (<1) and reduced correlation and largely be attributed to resolution
- Much smaller impact on TEMPO

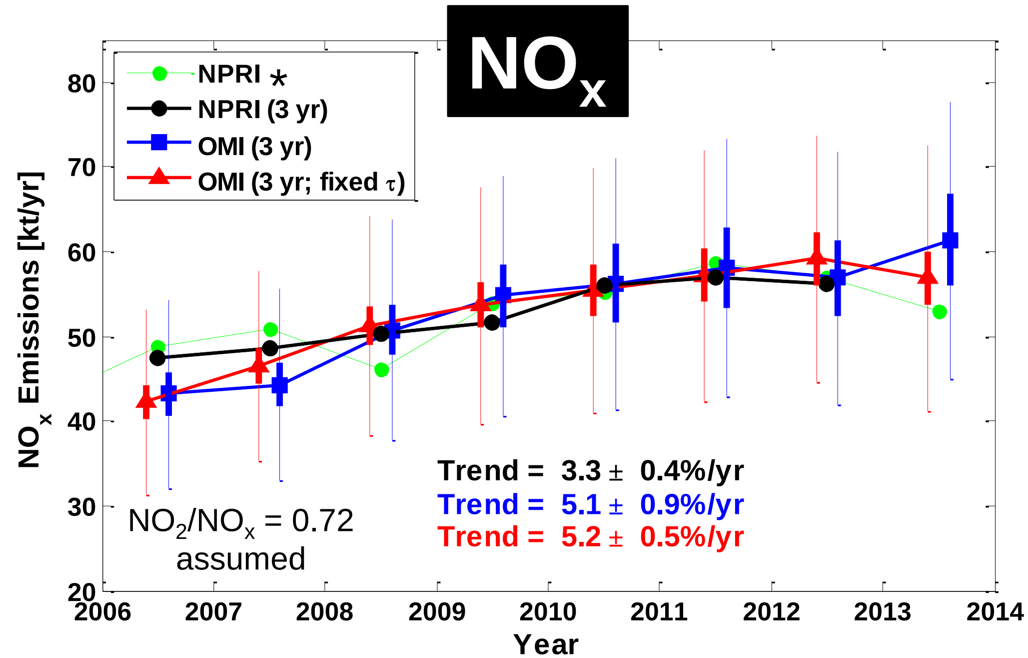
Surface SO_2 – 2005 annual mean

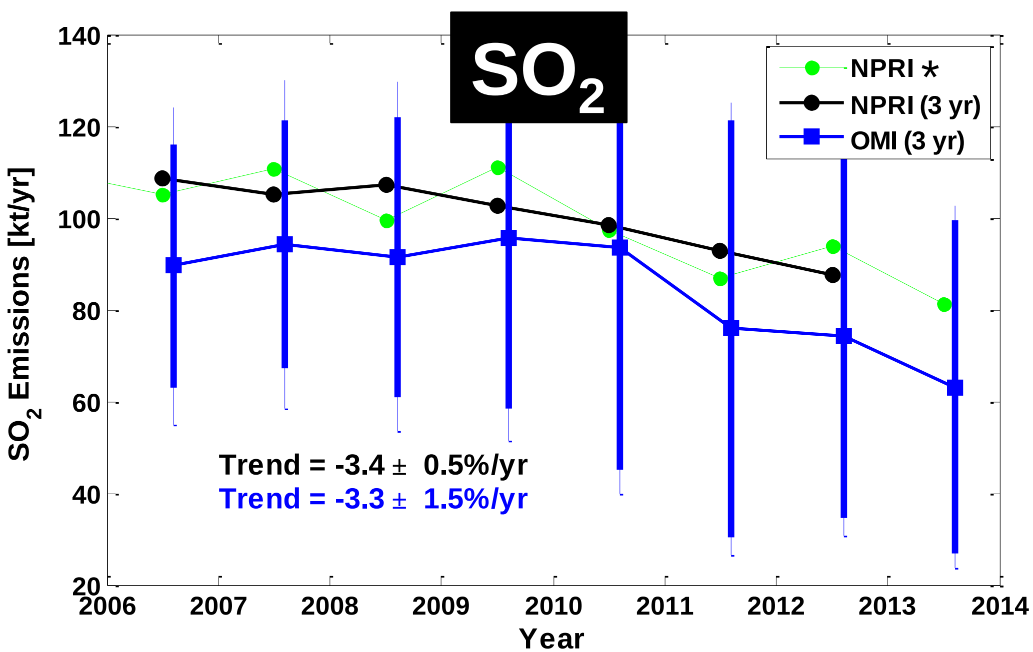






Alberta Oil Sands





Research Activities – Emissions Monitoring

- Method tracks downwind decay of pollutant (Fioletov et al., 2015)
  - Analogous to Beirle et al. (2011)
- τ_{NO2} = 2.5±0.3 hours
- τ_{SO2} = 4.2±0.5 hours
  - Short lifetimes !!
- If all NO_2 lost via NO_2 + OH
  [OH] = 1 / (τ_{NO2}·k)
  ≈ 10^7 molecules/cm^3
- ~1.5x10^7 molecules/cm^3 seen in plume
- consistent with large source of VOCs from mine face

* NPRI – National Pollutant Release Inventory

Validation Activities

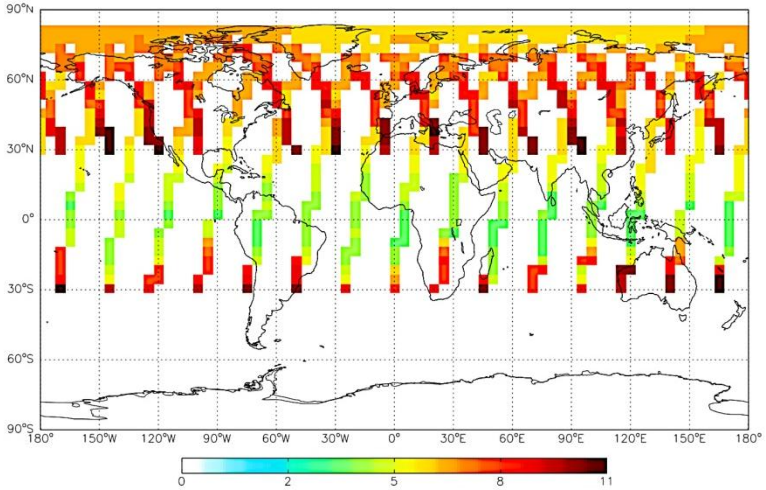
- EC deploying Pandora spectrometers to select monitoring sites
  - First four sites: Toronto, Oil sands, CARE (N of Toronto), Edmonton
  - 6+ should be in place for TropOMI validation
  - 8+ expected for TEMPO validation

- Aircraft campaigns:
  - Aircraft campaign being planned for 2016/17 (possibly winter)\
  - Support at EC for TEMPO validation campaign

Additional Material

∫CATS Observing System Simulation Experiment (OSSE)

NO$_2$ (ppb) a 30 km for LTAN = 1900, May 25

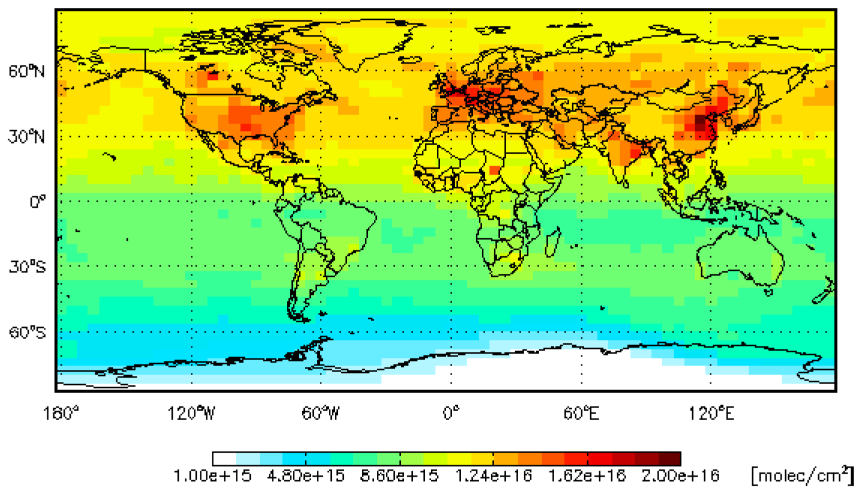


Generate pseudo-data by sampling GEOS-Chem along the ∫CATS orbit to produce O_3 (10 – 50 km) and NO_2 (10 – 40 km) data.

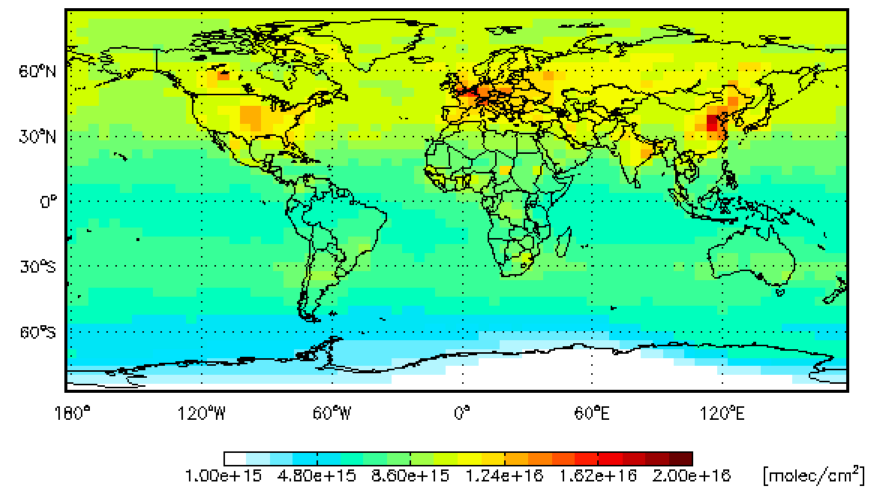
- Use GEOS-Chem with an increased source of stratospheric NOx to provide a biased a priori stratosphere.
- Assimilate pseudo-data for April 1 – May 31, 2013, assuming:
  - NO_2 precision is 1×10^8 cm^{-3} for $z > 17$ km and 2×10^8 cm^{-3} for $z \leq 17$ km
  - O_3 precision is 5% for $z \geq 26$ km and 10% for $z < 26$ km
  - A 50% uncertainty on the modeled NO_2 concentrations
- Data are assimilated using a sequential Kalman filter (following Parrington et al. [2008]) to optimize the stratospheric NO_2 distribution at a resolution of 4° x 5°.

Impact of assimilated CATS data on the stratosphere

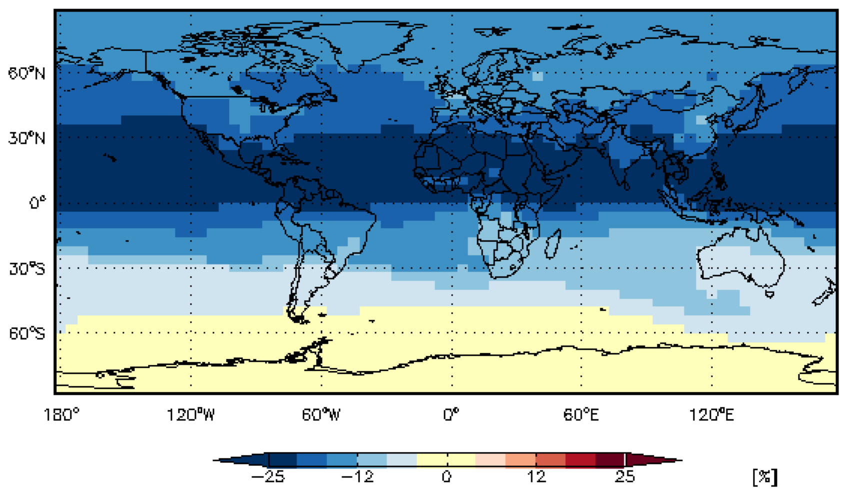
NO_2 column (a priori bias) for May 25, 2013



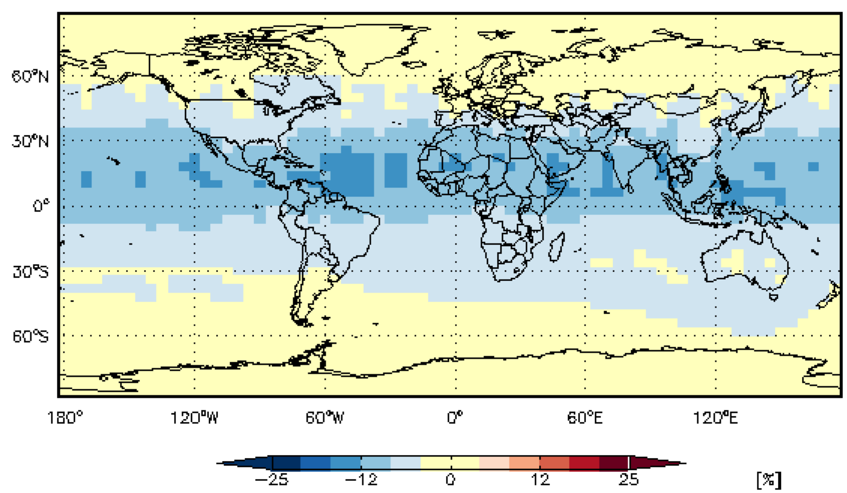
NO_2 column (true state) for May 25, 2013



Relative (%) a priori bias (true – prior)

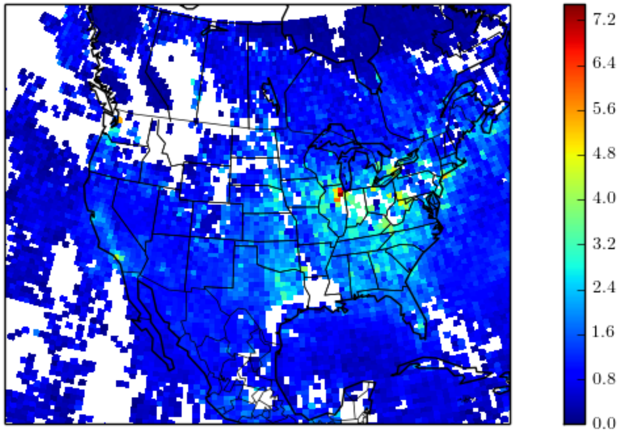


Relative (%) residual bias (true – assim)

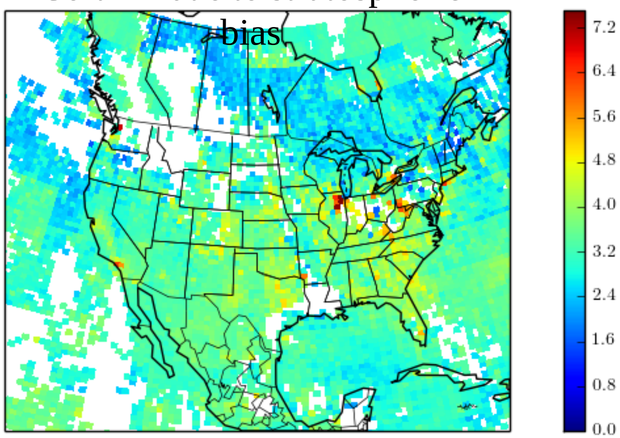


- Assimilation reduced the bias in the northern hemisphere (averaged 30-60N, May 15-31) from 20.4% to 5.6%.
- Properly accounting for the spatial correlations in the assimilation should further reduce the residual bias.

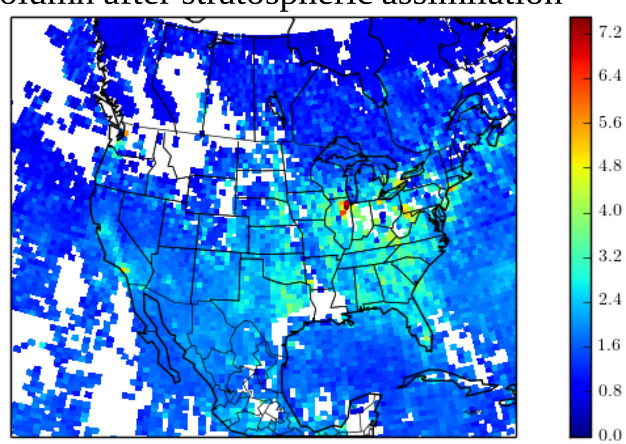
True tropospheric column (10^{15} cm^{-2})



Column due to stratospheric bias



Column after stratospheric assimilation



Impact on Tropospheric NO_2 Columns (May 15-31, 2013)

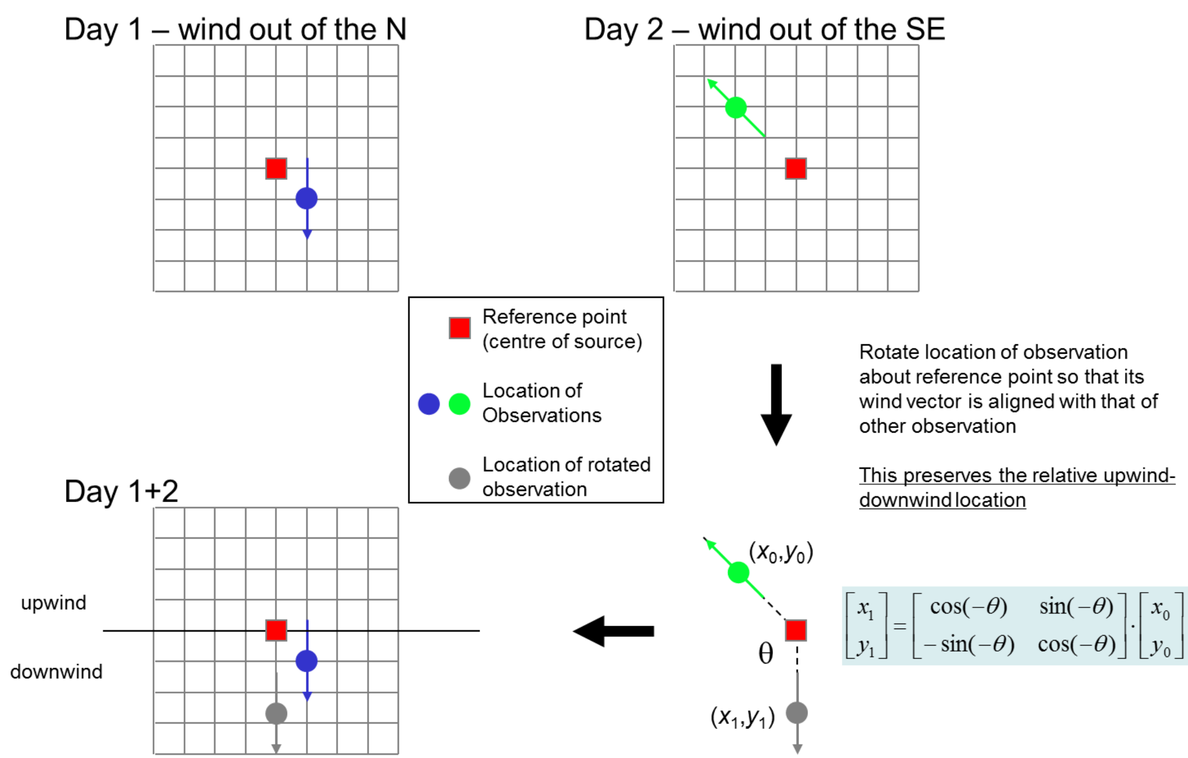
- Biased tropospheric NO_2 columns obtained by transferring the stratospheric bias onto OMI tropospheric NO_2 columns.
- With assimilation of ∫CATS data in the stratosphere, the impact of the stratospheric bias on the tropospheric NO_2 columns is significantly reduced.

Next Steps

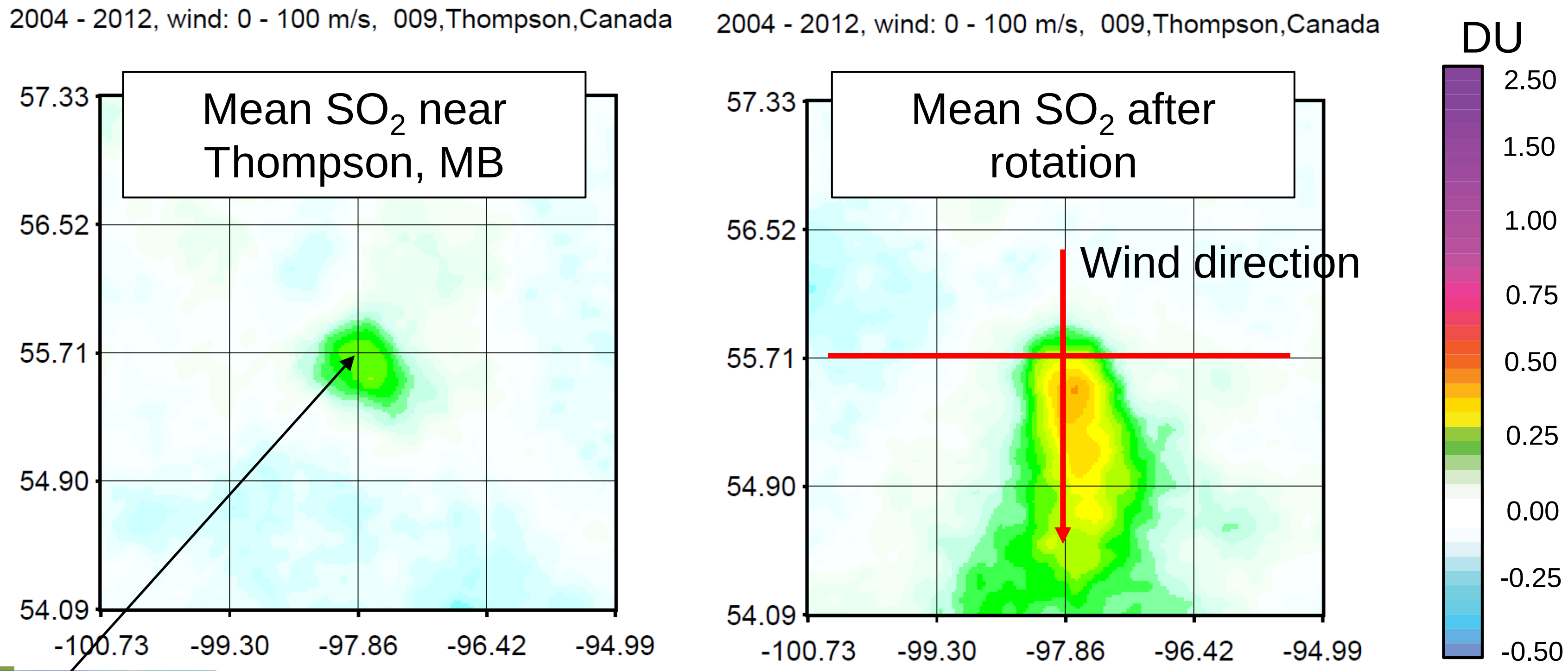
- Refine the stratospheric assimilation to reduce the residual stratospheric bias.
- Quantify the impact of the stratospheric bias on North American NOx emissions through inverse modeling of pseudo-data from TEMPO and TROPOMI with the nested GEOS-Chem model.

Merging satellite data and meteorology

- Methodology relies on a ‘rotation’ scheme:
  - Rotate location of all observations about a specified reference point (the source) so that their wind vectors are aligned
  - This preserves the relative “downwind-upwind” direction
  - Treat rotated data as a “climatological plume”



Merging satellite data and meteorology



Downwind decay of pollutants can be studied using a rotation scheme in which the locations of all observation are adjusted so that the have a common wind-direction

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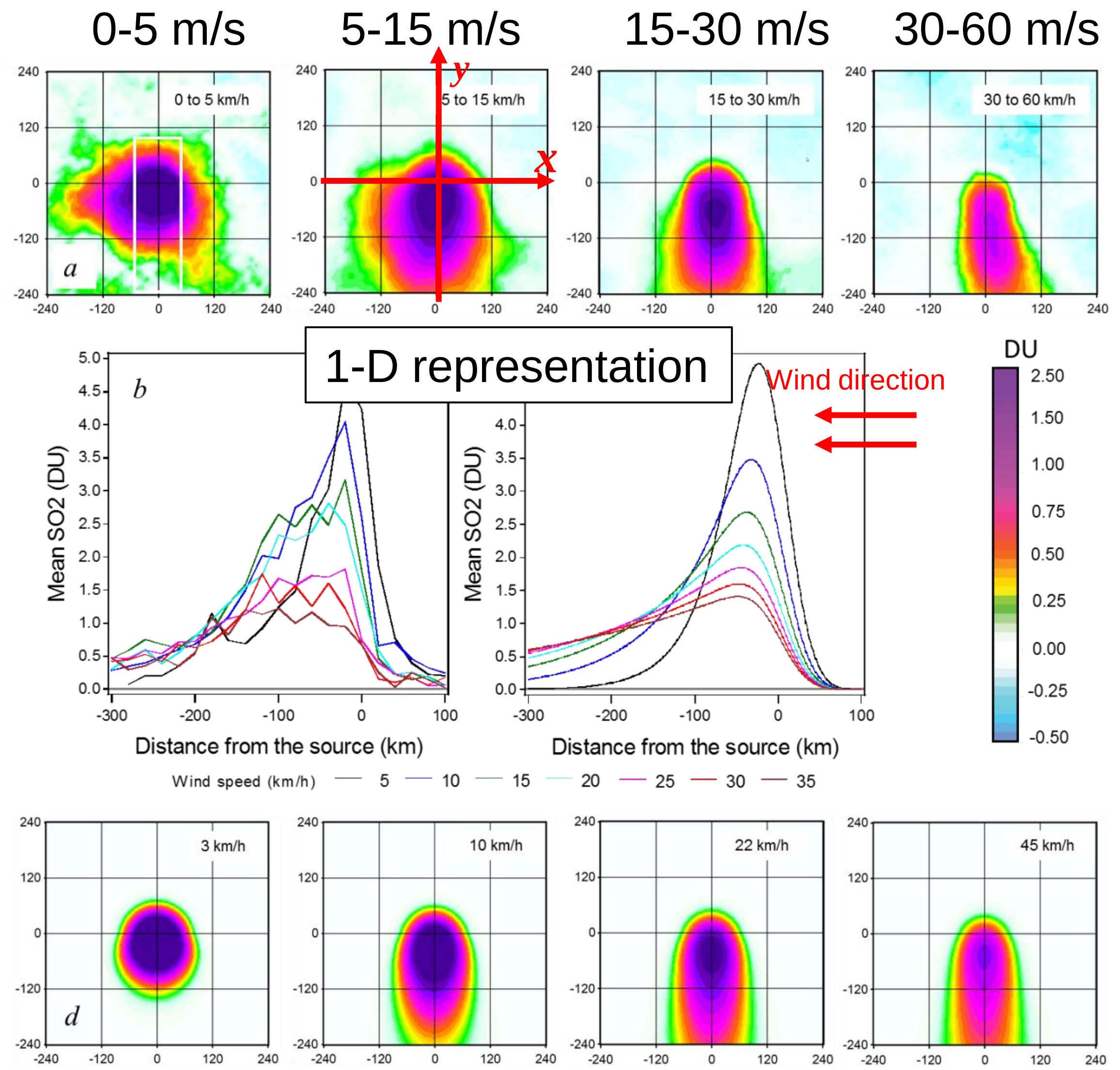
Emissions – Example using Norilsk

from *Fioletov et al.*, 2015

Maps using 'rotated' data →



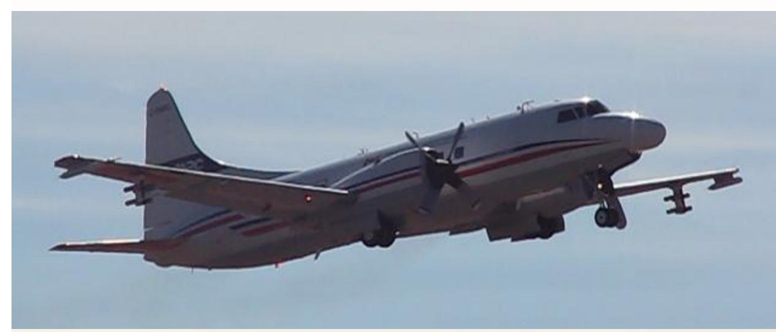
m and τ are determined by fitting the data to a function:
$OMI_{SO2} = a\, f(x,y)\, g(y,w)$

$f(x, y)$ - Gaussian function,
$g(y, w)$ - Exponentially modified Gaussian function;
w - windspeed

Non-linear fits to 'rotated' data →

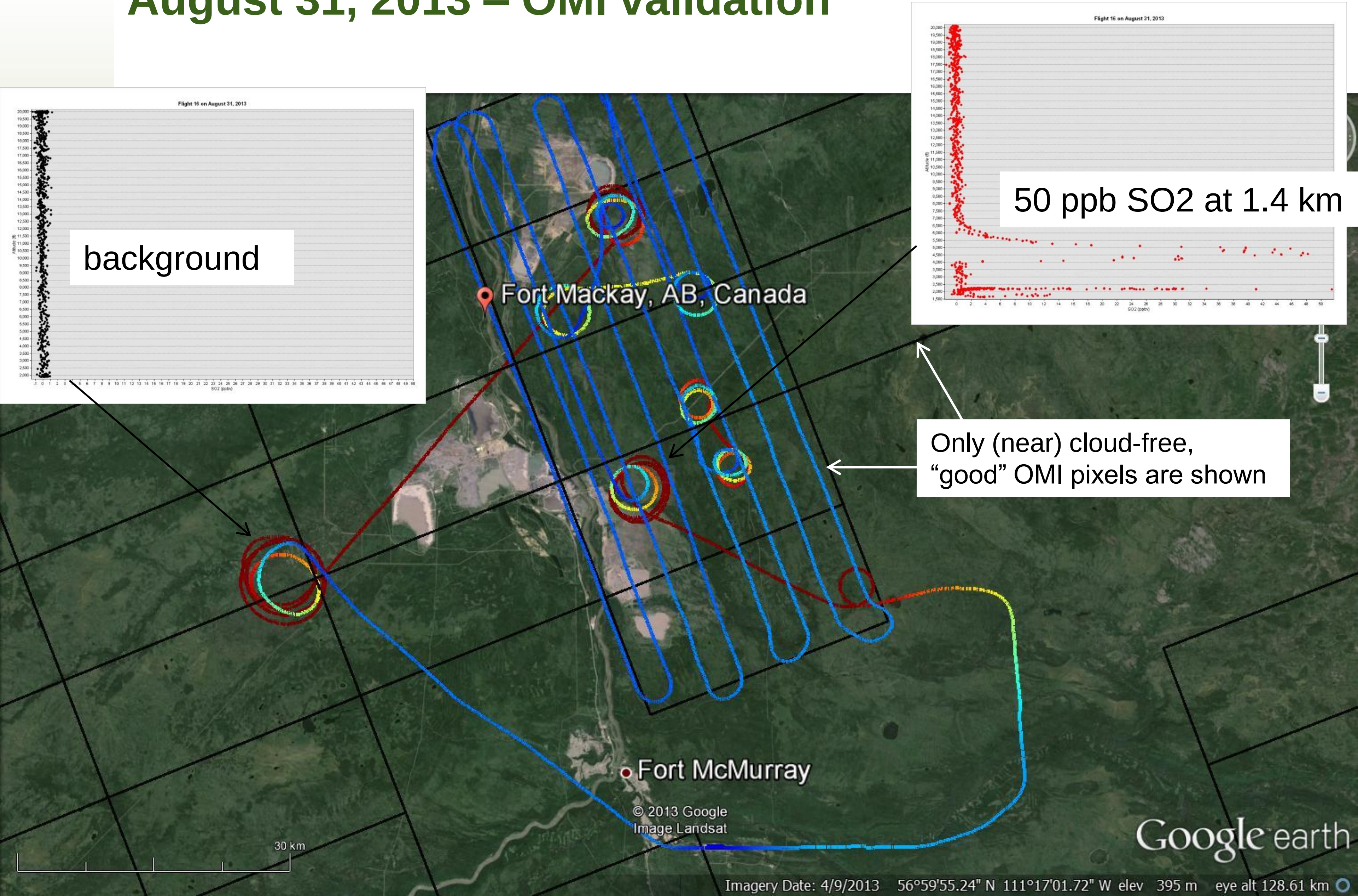
Summer 2013 Measurement Intensive: Aircraft + 2 supersites

- National Research Council Convair-580
- High time resolution measurements:
  - Particle size and speciation
  - Particle number as a function of size (6 nm to 20 μm).
  - Black carbon aerosol mass
  - Meteorology, including 3D winds and turbulence
  - Gases: SO_2, NO, NO_2, NO_x, CO, CO_2, CH_4, H_2O, NH_3, HCHO, H_2O
  - VOCs, measured using three methods:
    - 150 hydrocarbon suite (canisters),
    - Carboxylic acids, inorganic acids, isocyanic acid, substituted phenols (CIMS)
    - Non and substituted VOCs (PTR-MS)



From Shao-Meng Li, EC

August 31, 2013 – OMI validation



Pandora Network

Pandora

2013: Toronto, oil sands
2015: Egbert, Saturna
2016: Edmonton, oil sands (2)
2017: tbd x 2