The POLARCAT Model Intercomparison Project (POLMIP) aims to exploit the large number of observations collected in the Arctic troposphere as part of International Polar Year in 2008, to evaluate 10 state-of-the-art atmospheric chemical transport models.

**Louisa Emmons**, Simone Tilmes (NCAR) – **MOZART-4, CAM-chem**
**Steve Arnold**, Sarah Monks (Univ. of Leeds) – **TOMCAT**
Kathy Law, Solene Turquety, Jennie Thomas, Idir Bouarar (IPSL, Univ. Pierre et Marie Curie, Paris) – **LMDZ, WRF-chem**
Bryan Duncan, S. Steenrod, S. Strode (NASA Goddard) – **GMI**
Vincent Huijnen (KNMI) – **TM5**
Johannes Flemming (ECMWF) – **C-IFS**
Jingqiu Mao (GFDL) – **GEOS-Chem**
<table>
<thead>
<tr>
<th>Model</th>
<th>Resolution</th>
<th>Meteorology</th>
<th>Chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOMCAT</td>
<td>2.8°x2.8°, 31 levels</td>
<td>ECMWF ERA-oper.</td>
<td>trop: 82 species</td>
</tr>
<tr>
<td>MOZART-4</td>
<td>1.9°x2.5°, 56 levels</td>
<td>GEOS-5</td>
<td>trop: 103 species, bulk aerosols; photolysis options: FTUV: online; LUT: lookup table</td>
</tr>
<tr>
<td>CAM4-chem</td>
<td>1.9°x2.5°, 56 levels</td>
<td>GEOS-5</td>
<td>MOZART-4, bulk aerosols</td>
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<tr>
<td>CAM5-chem</td>
<td>1.9°x2.5°, 56 levels</td>
<td>GEOS-5</td>
<td>MOZART-4, modal aerosols</td>
</tr>
<tr>
<td>LMDZ-INCA</td>
<td>1.9°x3.75°, 19 levels</td>
<td>ECMWF</td>
<td>trop: 89 species</td>
</tr>
<tr>
<td>C-IFS</td>
<td>T159 (~1°), 60 levels</td>
<td>ECMWF</td>
<td>trop: CB05, strat: linear. O3 (Cariolle)</td>
</tr>
<tr>
<td>TM5</td>
<td>2°x3°, 60 levels</td>
<td>ECMWF</td>
<td>trop: CB05</td>
</tr>
<tr>
<td>NASA GMI</td>
<td>2°x2.5°, 72 levels</td>
<td>GEOS-5</td>
<td>strat&amp;trop (154 species), GOCART aer.</td>
</tr>
<tr>
<td>GEOS-Chem</td>
<td>2°x2.5°, 47 levels</td>
<td>GEOS-5</td>
<td>trop: ~100 species</td>
</tr>
<tr>
<td>WRF-Chem</td>
<td>100, 50, 25 km</td>
<td>NCEP GFS</td>
<td>MOZART-GOCART</td>
</tr>
</tbody>
</table>

**Emissions – Same for all models:**
- Anthropogenic: Streets’ ARCTAS-v1.2
- Fires: FINN-v1
- Biogenic, Ocean, etc: MACCity

*GEOS-chem used slightly different anthropogenic emissions and includes increased HO_2 aerosol uptake [Mao et al., ACPD, 2012]*

**Output:**
- Monthly for all of 2008
- Hourly for Spring & Summer for comparison with field campaigns
- Focus on gas-phase chemistry
- Artificial tracers – 25-day lifetime, based on CO anthropogenic and fire emissions
Artificial 25-day tracers with CO emissions from 3 regions
Allow comparison of purely dynamics between the models, without chemistry

Averages over poleward of 66N

All models show same general patterns:
- Anthro emissions dominate in winter
- Asia fires significant in spring and summer
- Europe anthro is major source in DJF lower trop
- In summer Asia is largest anthro source in UT

Largest differences between models in fire tracers

Sarah Monks, in preparation
The HTAP models, with various emissions, had difficulty reproducing Arctic observations; POLMIP models which all use the same emissions, show smaller differences, but still show deficiencies.
POLARCAT Experiments
April-July 2008

Spring:
NASA – ARCTAS (Alaska)
NOAA – ARCPAC (Alaska)
POLARCAT-France (Sweden)
{May-June: START08 (NCAR-GV, N.Amer.)}

Summer:
NASA – ARCTAS (Canada)
DLR – GRACE (Greenland)
POLARCAT-France (Greenland)
Comparison to DC-8 obs – all models interpolated to flight tracks, then binned by alt.

Large differences in model CO indicate model chemistry and OH differences (over Alaska)
DC-8 flights over Canada and the Arctic
– some flights focused on fires in Saskatchewan
POLMIP models – OH and Cloud zonal averages – monthly mean - April

**OH Zonal Average - Apr**
- CAM4-chem
- CAM5-chem
- MOZART-4/lut
- TOMCAT
- TM5
- C-IFS
- GMI-GEOS5
- GEOS-Chem

**Cloud Fraction - Apr**
- CAMChem_GEOS5
- CESM1_CAM5Chem_GEOS5_tune
- MOZART4lut
- TOMCAT
- TM5
- CIFS_v2
- gmi-geos5
- GEOSChem

1E5 molecules/cm³

Pressure vs. Latitude
POLMIP models – OH and Cloud zonal averages – monthly mean - July
Photolysis Rates

Photolysis rates differ significantly between models. The differences in photolysis rates are probably the main source of variations in OH and O₃.

For example:

\[ J(O_3 \rightarrow O^{1}D) \text{ & } O^{1}D + H_2O \rightarrow 2 \text{ OH}, \text{ is a principal term for ozone loss, as well as OH production} \]

\[ J(H_2O_2) \rightarrow 2 \text{ OH} \text{ is another key OH source} \]

Differences in the cloud distributions between models is a key factor in the photolysis differences.

Photolysis rates, based on actinic flux observations made on the NASA DC-8 can be used for model evaluation... if hourly Js are output!

Black: Obs (Sam Hall, NCAR); Red: CAM-chem; Blue: MOZART-4/FTUV
Ozone Budget

The individual tropospheric ozone production and loss rate terms have been saved from a MOZART-4 simulation. In both April and July, the most active ozone chemistry is in East Asia and the eastern US. The Siberia region contains primarily fire emissions (little anthropogenic) yet shows significant ozone production. Over the Arctic and ocean regions there is greater loss than production.
Significant differences between models in OH, HO$_2$, ozone precursors over major source regions
Fire Emissions - Observed Enhancement Ratios from ARCTAS DC-8 observations [Hornbrook, Apel, et al., ACP, 2011]
Fire Emissions – Modeled VOC/CO correlations compared to emissions and observations

Modeled ratios match emissions for NMHCs, but not species also produced chemically
C2H6 fire emissions slightly high, propane too low, ethanol much too low
Modeled acetone low – due to chemistry or emissions? or both?
Asian plume (anthro+fire) sampled by DC-8 July 9

Model CO profiles sampled along mean plume trajectory.
Lagrangian model initialised 18UT 7 July

5-day CiTTyCAT Lagrangian box model simulations initialised with POLMIP model concentrations.
Summary & Conclusions

- Transport of mid-latitude sources into Arctic is broadly consistent between models.
- Models vary widely in their simulation of ozone precursors in the Arctic – esp. for NOy and oVOC species.
- Differences in ozone production and loss in Arctic between models is controlled by NOy partitioning and oVOC chemistry.
- Model differences in OH are likely due primarily to differences in photolysis rates, which are affected by model-simulated clouds and their treatment in the photolysis schemes.
- Hydrocarbon oxidation schemes in models impact the OH budget, as well.

Model evaluations need to include comparisons of ozone precursors, as well as ozone. Multi-model assessments such as these can lead to valuable insights in model performance, but require a large number of parameters to be provided by each model group.