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Modeling In-Flight Aircraft Emissions

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What are the relative effects of in situ vs. boundary layer emissions sources on aerosols in the upper troposphere?

upper troposphere

boundary layer

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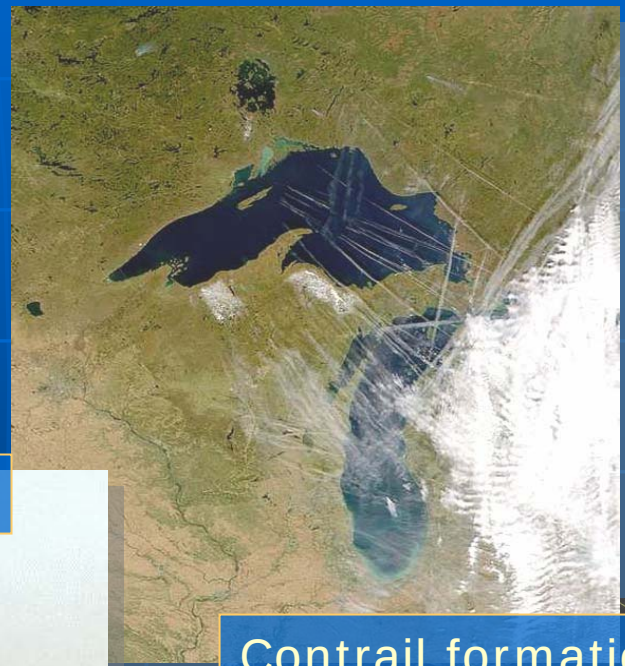
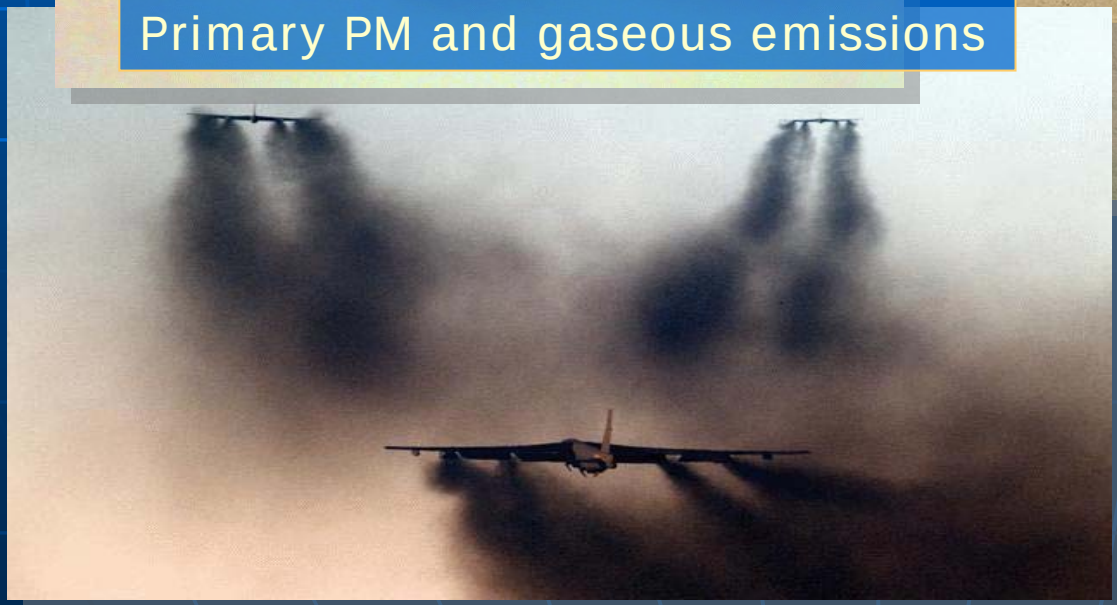
How do aircraft emissions affect aerosol loading in the free troposphere?

Primary PM and gaseous emissions



Contrail formation



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Why study emissions in the upper troposphere?

- Few emissions sources in a relatively pristine part of the atmosphere
- Cloud formation and aerosols from aircraft affect radiative transfer
  - Climate implications
  - Boundary layer pollution impacts through photochemistry
- Impacts on stratospheric O_3

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Approach

- Study the affects of anthropogenic emissions in the upper troposphere (< ~10-20km)
- Model 3-d in-flight aircraft emissions inventories with SMOKE
- Use modeled aircraft emissions in CMAQ and compare with measurements from flight campaigns

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Approach

- Hybrid area/point source inventory required modifications to SMOKE
  - Area-like: Horizontal spatial allocation using surrogates
  - Point-like: Calculate vertical layer fractions using emissions altitudes
- New aircraft inventory IDA format
  - Based on point format, replaces plant ID with emissions altitudes from inventory

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Data Sources
Inventory

- 1999 Boeing Scheduled Civil Aircraft Emissions database
  - 1^o x 1^o x 1 km 3-d gridded inventory
  - Monthly, annual estimates of fuel use, CO, NO_x, and total hydrocarbons
  - Emissions factors for deriving H_2O vapor, CO_2, soot, and SO_2 emissions
  - Global coverage up to 19 km altitude
- New program *boeingtoida* to convert to SMOKE format and assign FIPS codes

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Data Sources
Temporal and Chemical Profiles

- Temporal Profiles
  - 0-8km: landing-takeoff (LTO) activity information from U.S. EPA
  - > 8km: NASA commercial flight track database for all U.S./Canadian air traffic, year 2000-present
- VOC speciation
  - SPECIATE 3.2 aggregate exhaust profile 1098[1]
- PM emissions
  - Soot emissions factor: 0.04 g EC/kg fuel use[2]

[1]Spicer et al. (1994) *Annales Geophysicae*. 12, pp. 944-955.

[2]Schumann et al. (1998) *Atmospheric Environment*. 32, pp. 3097-3103

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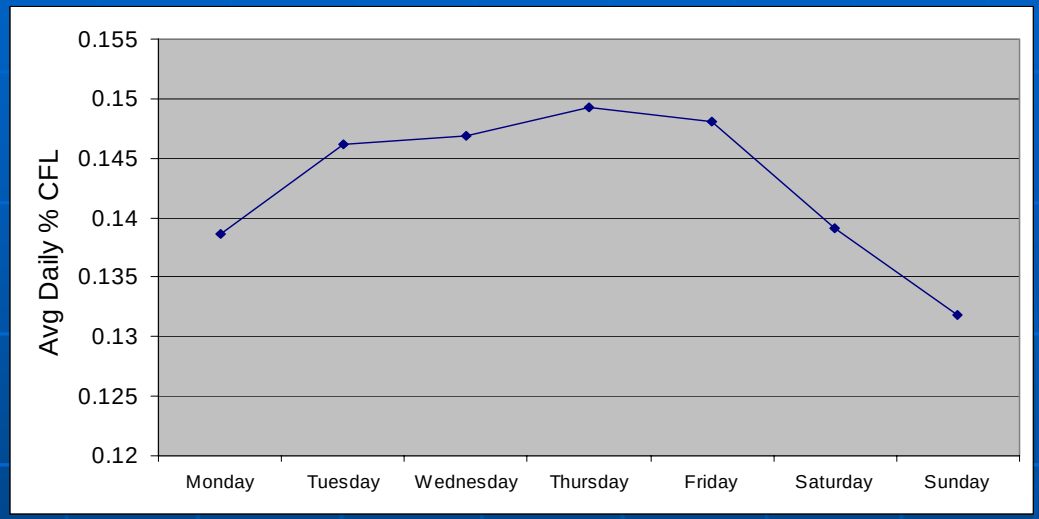
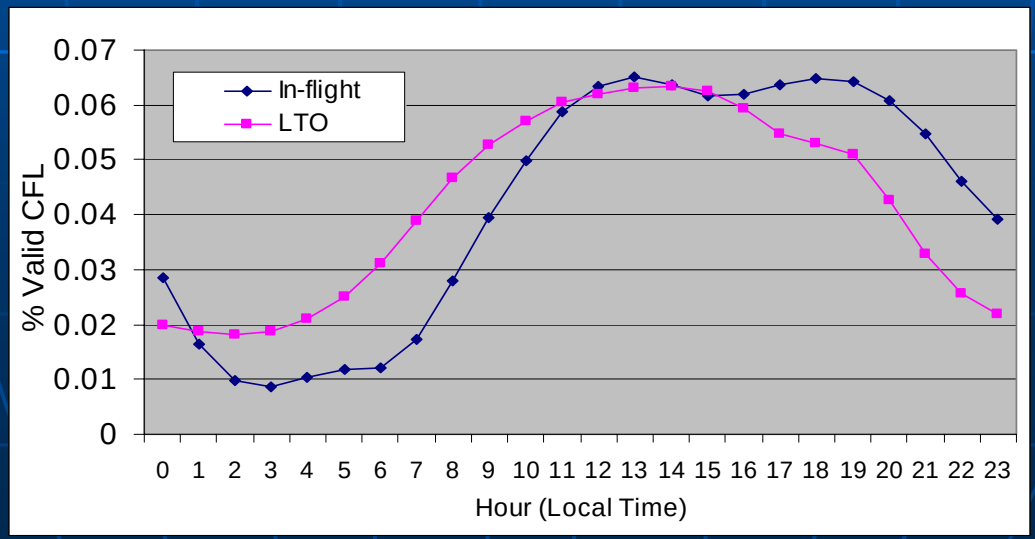
In-flight Aircraft Temporal Profiles

Weekly:



Diurnal:



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Data Sources
Spatial Surrogates

- Gridded 1^{o} x 1^{o} inventory with latitude-longitude coordinate of lower-left corner of data cells
- Synthetic FIPS codes roughly based on time zone boundaries (~14^{o}-21^{0} latitude increments)
  - State code: time zone code
  - County code: inventory cell
- Overlay the time zone-based grid on a model grid using a GIS

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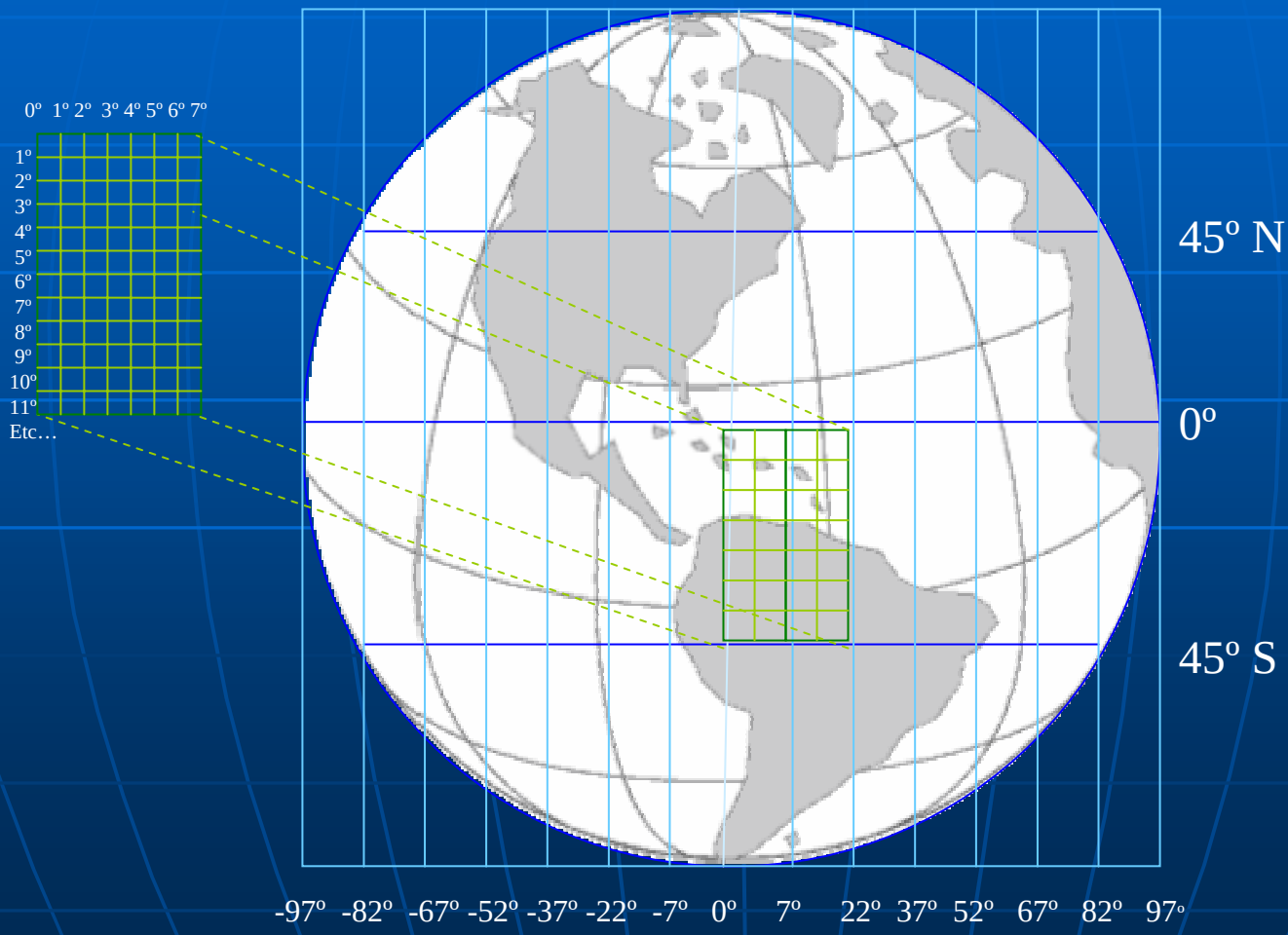
Aircraft Inventory Data Grid



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SMOKE Updates

- Modified inventory reader (Smkinven) to accommodate the new aircraft IDA format; reads and stores emissions altitudes
- New global environment variable, USE_AIRCRAFT_DATA
- Modified vertical allocation routine (Laypoint) to calculate layer fractions based on emissions altitudes
- Add all global time zones with hour offsets from GMT to accommodate global aircraft inventory

SMOKE Results

- SMOKE outputs CO, CO_2, speciated VOC, NO, NO_2, SO_2, EC, H_2O, and fuel use
- Vertically-dependent diurnal profiles
- Inventory grid mapped continuously to model grid
- 108 km grid resolution trans-Pacific test simulation for January, 2001

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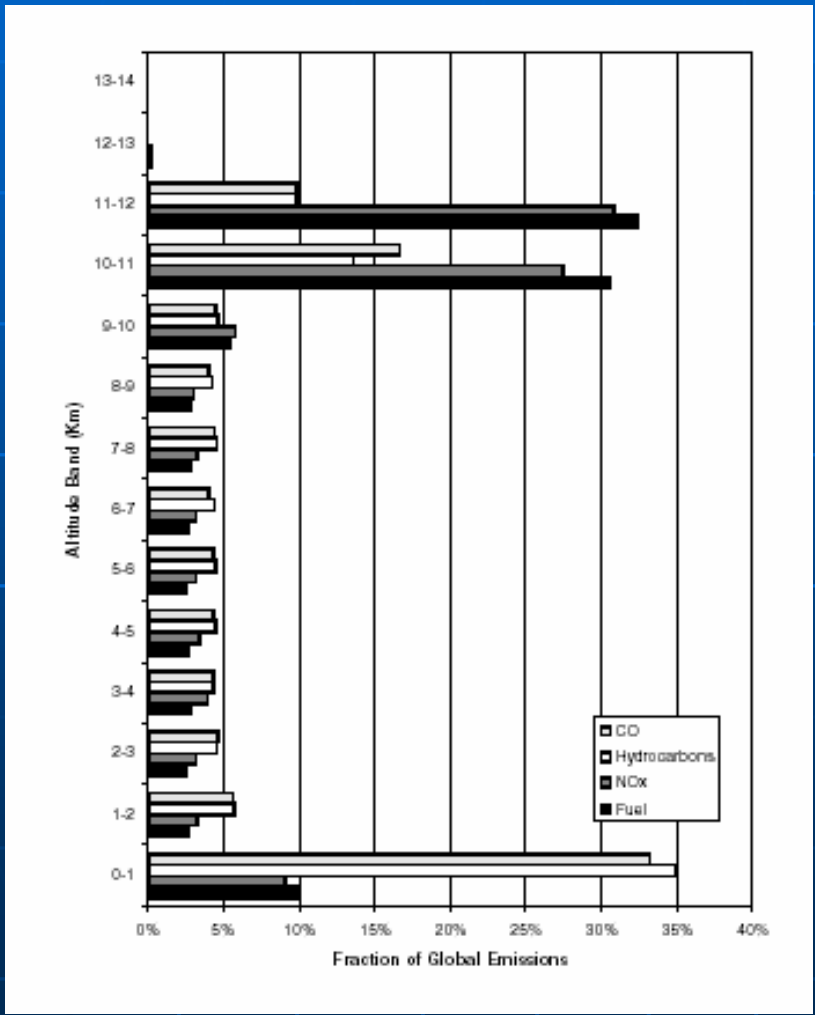
Inventory Summary by Altitude



- CO and VOC emissions peak in 0-1 km band
- NOx and fuel use peak > 10 km
- Compare with SMOKE outputs

Adapted from Sutkus et al. (2001) NASA/CR-2001-211216

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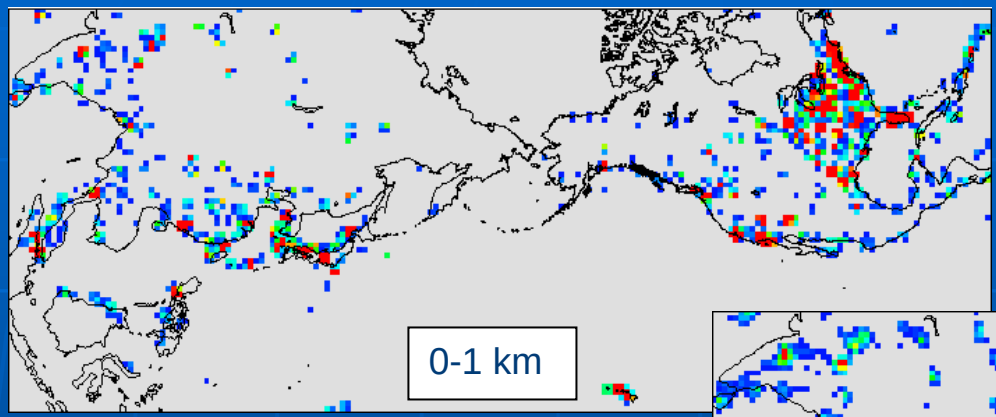
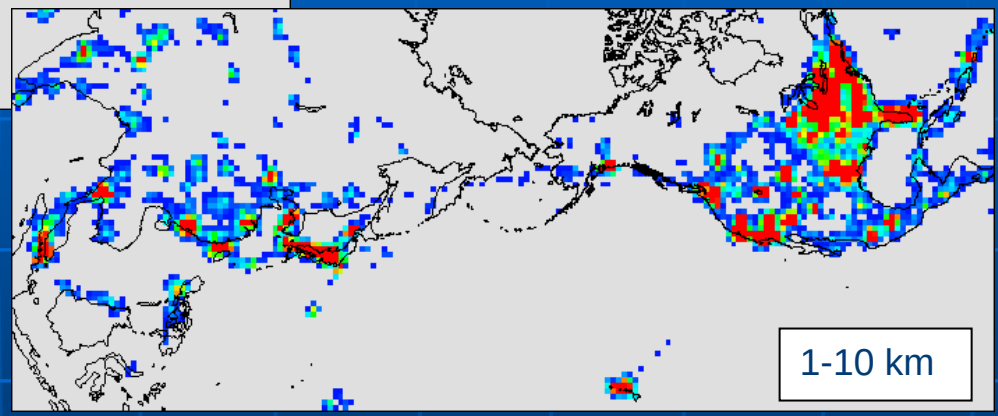
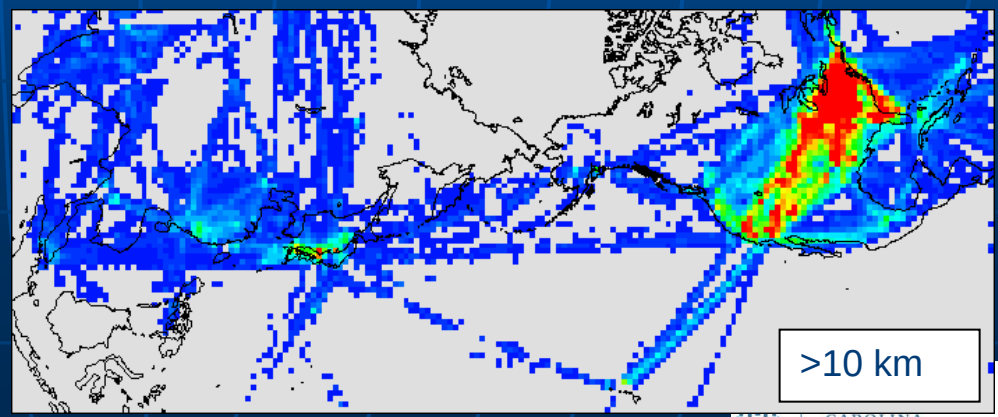
SMOKE Output

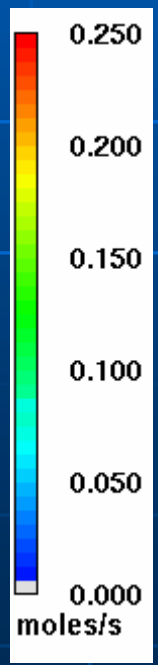
CO Emissions



- January 1, 2001 Maximum CO







- LTO, ascent/ descent, cruising altitude bands

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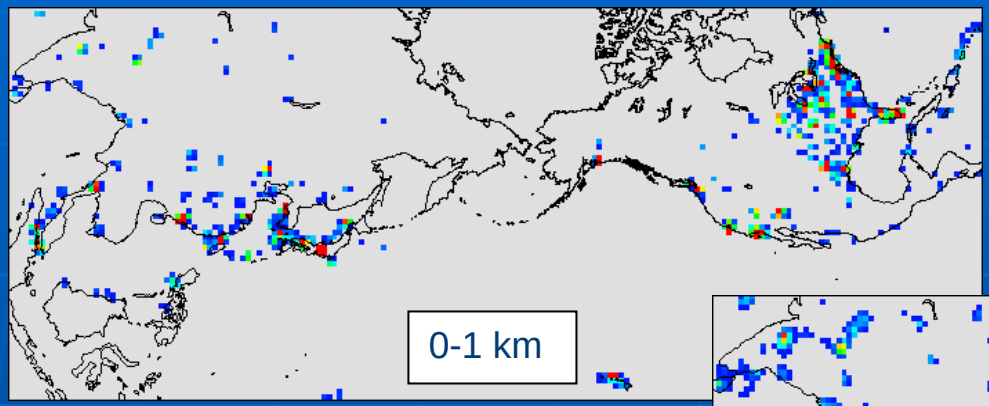
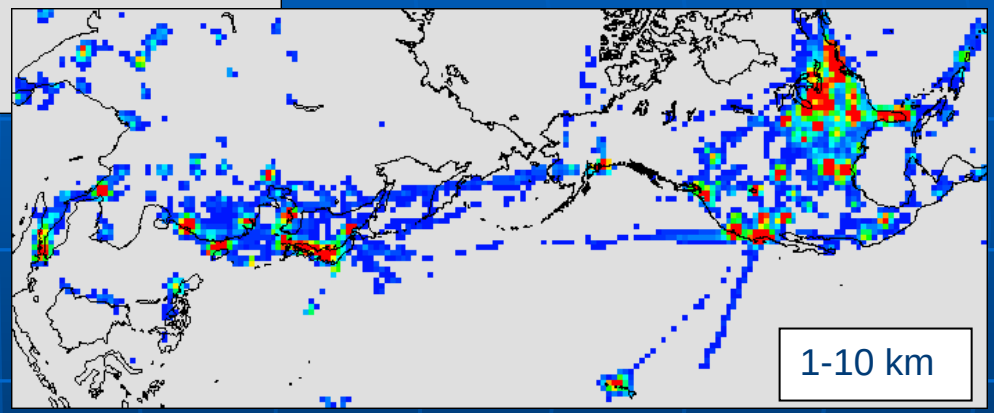
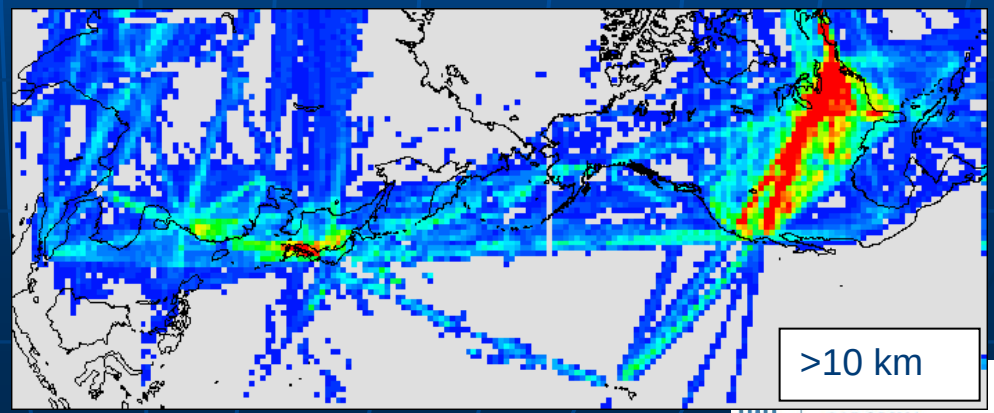
SMOKE Output

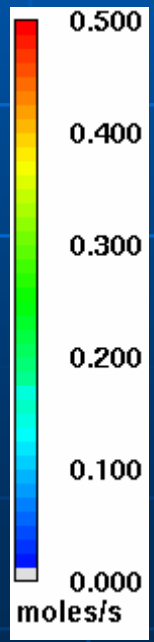
NOx Emissions



- January 1, 2001 Maximum NOx







- LTO, ascent/ descent, cruising altitude bands

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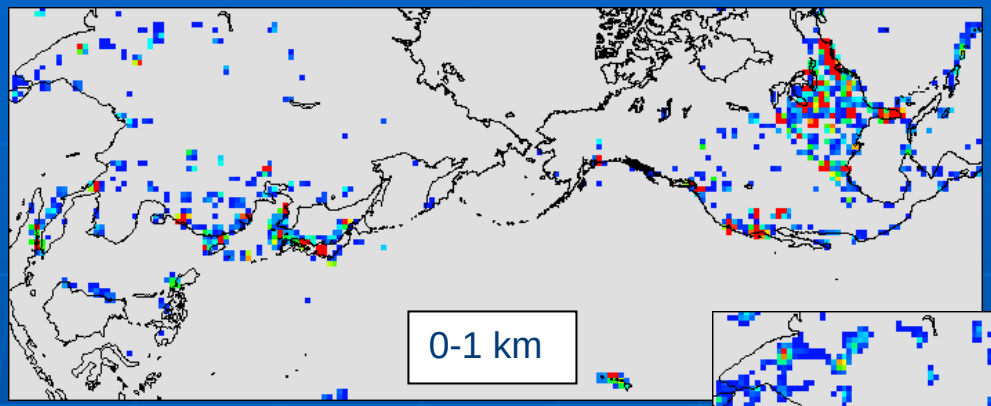
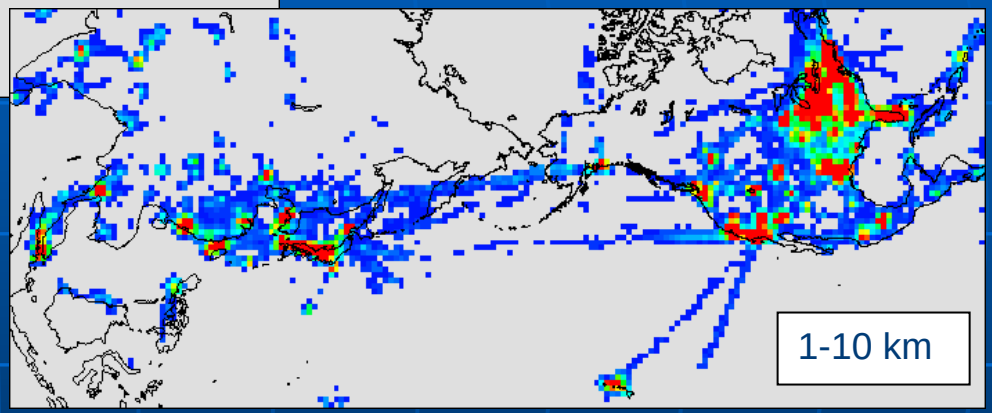
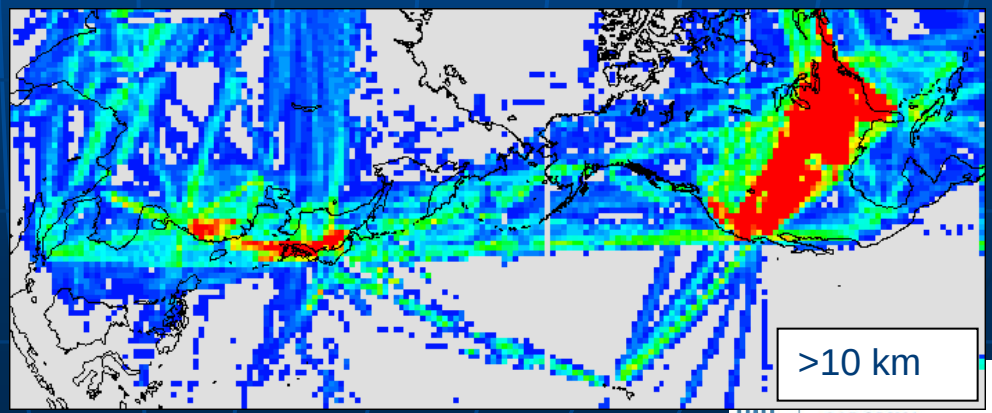
SMOKE Output

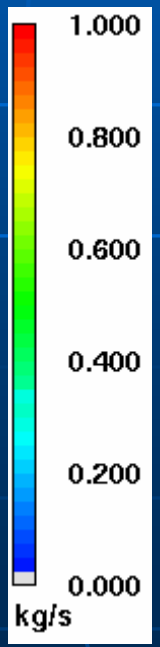
Fuel Use



- January 1, 2001 Maximum Fuel Use







- LTO, ascent/ descent, cruising altitude bands

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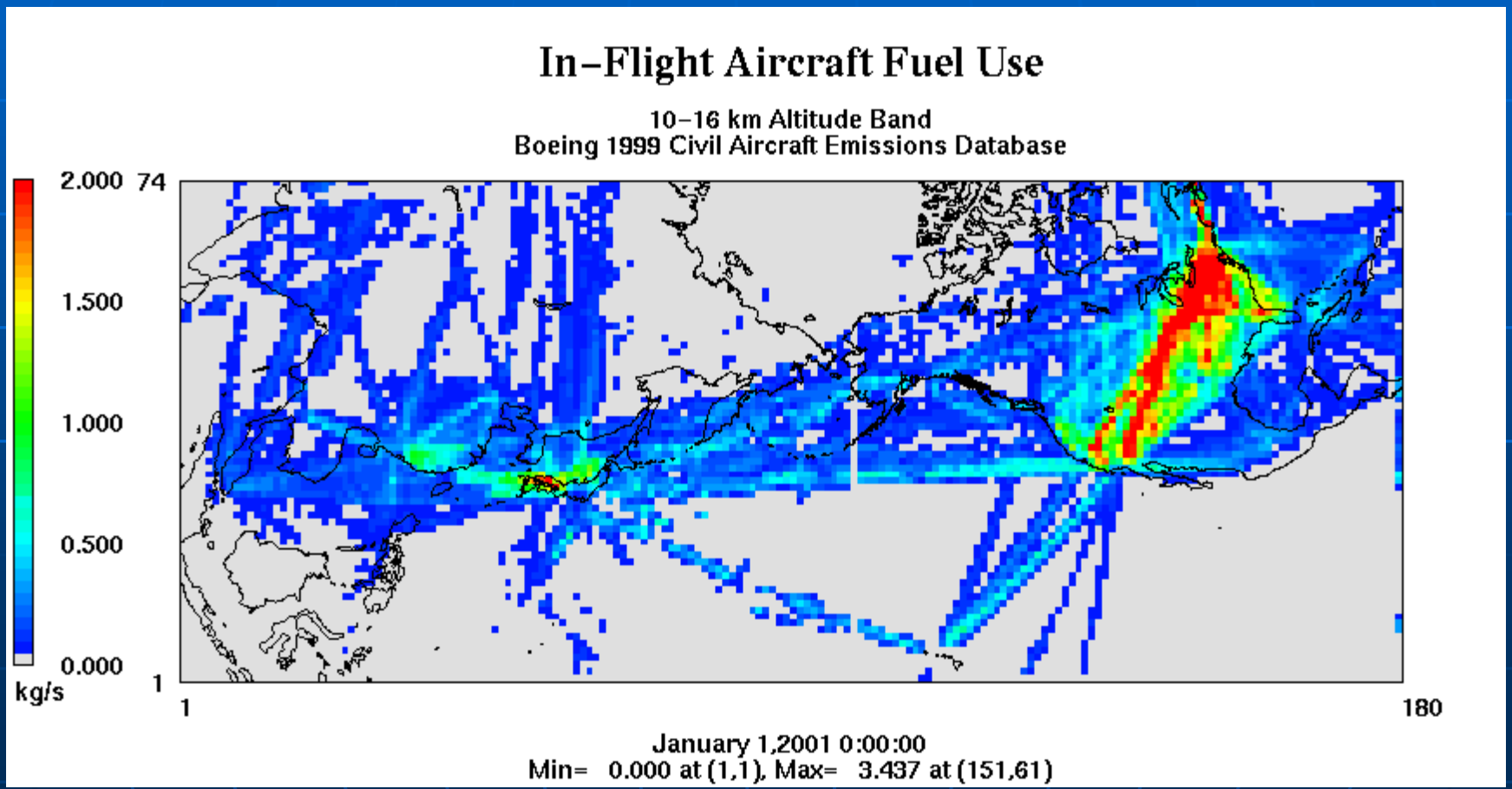
SMOKE Output
Temporal Variability in Fuel Use



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Conclusions

- Next step is to model these emissions in CMAQ and compare PM predictions with free troposphere measurements from aircraft campaigns
- Explore improvements to diurnal profiles over oceans
- Model emissions at finer grid scale resolutions
- Aircraft code available for beta release now, official release with SMOKE in October, 2005

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- And of course…

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Go Heels!

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