Nitrogen, Oxidants, Mercury and Aerosol Distributions, Sources and Sinks (NOMADSS): An NSF sponsored airborne experiment integrating the NAAMEX, TROPHONO and SOAS studies

Dan Jaffe, University of Washington
Alex Guenther, National Center for Atmospheric Chemistry
Xianliang Zhou, Wadsworth Center and SUNY Albany

The merger of the SOAS, NAAMEX and TROPHONO field campaign on C-130 platform provides several advantages and new opportunities for the three respective projects, with a few minor drawbacks, as summarized below:

SOAS: All of the SOAS objectives can be addressed by the merged airborne study including the direct quantification of VOC, ozone and NO_x surface fluxes and reconcile differences with "top-down" emission estimates; better understanding of HO_x/NO_x/ozone/organics/aerosol distributions, sources and sinks. While there are some limitations associated with using the C-130 instead of the Twin Otter, the additional measurement suite carried by the C-130 will improve the scientific results.

The addition of fast and highly accurate NO, NO_2, and Ozone measurements and TOGA VOC will greatly improve the core measurements for investigating VOC, NO_x and ozone fluxes and chemistry. In addition, the HO_x, HONO, and canister sampling will provide a comprehensive suite of measurements that will substantially extend the scientific questions that can be addressed. The OH measurements will be especially valuable for comparing with the OH estimated using isoprene flux divergence. The HONO, HO_2, RO_2 and aerosol measurements will provide constraints for characterizing processes controlling the oxidation of organics and production of ozone and secondary organic aerosol.

The limitations of the C-130 minimum flight altitude and speed are a slight disadvantage. This is due to the decrease in spatial resolution of the flux measurements and the increase in uncertainty of the estimated surface fluxes due to the greater flux divergence at higher flight altitudes. The complexity of coordinating the objectives of the three studies will be a challenge and will require careful coordination by the three mission scientists. Finally, the extended flight hours require that additional resources be identified to support the added personnel and operational costs that are not covered by the LAOF deployment pool.

NAAMEX: The primary goals for NAAMEX are to (1): constrain emissions of mercury from major source regions in the United States, and (2) quantify the distribution and chemical transformations of speciated mercury in the troposphere. These goals will be fully met in the merged project. The merger represents a significant opportunity to conduct detailed sampling in the most concentrated Hg source region in North America as well as flights into the middle and upper troposphere where models suggest a significant source of oxidized Hg. The NOMADSS payload includes the key NAAMEX measurements, plus fast VOC measurements that will help in source identification. The data on HONO will provide an additional constraint on oxidation processes, which are poorly understood for Hg.

One drawback to the merged project is the loss of the CIMS instrument. The UCLA DOAS may provide some useful information on BrO that will substitute for the CIMS data. An additional drawback is that we will not be able to fly as far north for the downwind outflow flights in the northeast U.S., due to the base in Nashville. Nonetheless, the extensive flight time over the major Eastern U.S. source region, combined with the GEOS-CHEM Hg model will provide important new constraints on the industrial Hg emissions. The Nashville base will allow sampling of the upper troposphere over Florida and Texas where the GEOS-CHEM Hg model predicts large concentrations of oxidized Hg.

TROPHONO: We will be able to accomplish all the originally proposed objectives during the merged field study, i.e., (1) to establish HONO distribution and budget in various air masses (continental and oceanic background air masses, and urban/industrial plumes) in the troposphere; (2) to collect bulk aerosol samples for laboratory photochemical experiments to measure photolysis rate constant of particulate nitrate leading to HONO and NO_x productions; (3) to quantify p-NO_3 as a daytime HONO source and a re-NOx-ification pathway in the troposphere; (4) to examine HONO production from photo-enhanced heterogeneous NO_x reactions in urban/industrial plumes; and (5) to investigate HONO dark formation/nighttime accumulation and morning-hour photolytic decay in the PBL and in the FT.

The most significant advantage of the merger is the availability of a suite important supporting parameters, such as OH, NO_x, and atmospheric turbulence, which would not be measured on the King Air as originally proposed. We will be able to examine more closely the HONO photo-steady state with the available OH and NO concentrations, and to assess more accurately the net *in situ* (volume) HONO production rate. We will be able to assess more accurately the contribution of ground source to the tropospheric HONO budget with the atmospheric turbulence information. In addition, more flight hours available in the merged field study (150 hr *vs* 80 hr) and longer flight ranges will allow us to collect more data in a larger variety of air masses covering a lager geographic region.

One minor drawback from the merger is that we are not able to fly close to the ground surface (~100 m on King Air *vs* ~300 m on C-130). Since the focus of this project is on the *in situ* processes leading to HONO production in the air column, this minor drawback will not result in any negative effect on the research.

Proposed flights for NOMADSS

Based on information from EOL and in consultation with the PI's of each project, a base in Nashville TN will allow us to achieve the maximum benefits from the merged project. Flight plans given below assume a Nashville base. Note that while we intend to conduct the flights listed below, the details on any given day can shift depending on meteorology and chemical model forecasts. Flights may also be adjusted due to air traffic and other operational requirements.

Table 1. Summary of the requested flights with objectives for each

Flight pattern	Objectives
1. Horizontal and vertical profiles over rural Eastern U.S. regions with various vegetation types, daytime, eight 8-hr flights requested, mid June to early July	
• Morning ~450-km horizontal transect at 300 m, to the target location for vertical profiling (~1.5 hr) • 6-level vertical profiling in a 70-km long racetrack pattern starting in the FT (6000 m, 4000 m, and 2000 m, 20 min at each level) and then in the PBL (just below the PBL top, middle of the PBL, and 300 m, 30 min at each level) (~3 hr) • Noontime ~275-km horizontal transect at 300 m (~1 hr) • 6-level vertical profiling in a 50-km long racetrack pattern starting in the PBL (300 m, middle of the PBL, and just below the PBL top, 30 min at each level) and then in the FT (2000 m, 4000 m, and 6000 m, 20 min at each level) (~2 hr) • Afternoon ~275-km horizontal transect at 300 m, back to the airport (~1 hr)	**SOAS objectives**: direct quantification of VOC, ozone and NO_x surface fluxes and reconcile differences with "top-down" emission estimates; better understanding of HO_x/NO_x/ozone/organics/aerosol distributions, sources and sinks. **NAAMEX objectives**: Characterization of major Hg source region, examination of vertical profile of Hg^0 and Hg^{+2}. **TROPHONO objectives**: Examination of horizontal and vertical distributions of HONO, HNO_3, pNO_3 and NO_x in the continental background air masses; collection of bulk aerosol samples for photochemical experiments in laboratory.
2. Horizontal and vertical profiles over rural Eastern U.S. regions with various vegetation types, early afternoon/night, one 7.5-hr flight requested, mid June to early July	
• Afternoon 150-km horizontal transect at 300 m, to the target location for vertical profiling (~0.5 hr) • 6-level vertical profiling in a 70-km long racetrack pattern starting in the PBL (300 m, , middle of the PBL, and just below the PBL top	**SOAS objectives**: direct quantification of VOC, ozone and NO_x surface fluxes and reconcile differences with "top-down" emission estimates; better understanding of HO_x/NO_x/ozone/organics/aerosol distributions, sources and sinks.

30 min at each level) and then in the FT (2000 m, 4000 m, and 6000 m, 20 min at each level) (~3 hr) • Time series, alternating at two altitudes: 500 m and 3000 m, ~20 min each, in 30-km diameter circles, starting ~1 hr before sunset. (~3.5 hr) • nighttime 150-km horizontal transect at 300 m, back to the airport (~0.5 hr)	**NAAMEX objectives**: Characterization of major Hg source region, examination of vertical profile of Hg^0 and Hg^{+2}. **TROPHONO objectives**: Examination of horizontal and vertical distributions of HONO, HNO_3, pNO_3 and NO_x in the continental background air masses; collection of bulk aerosol samples for photochemical experiments in laboratory; (3) examination of nighttime HONO formation and accumulation in the PBL and FT.
3. Horizontal and vertical profiles over rural Eastern U.S. regions with various vegetation types, early-late morning, one 7.5-hr flight requested, mid June to early July	
• Early morning 150-km horizontal transect at 300 m, to the target location for vertical profiling (~0.5 hr) • Time series, alternating at two altitudes: 500 m and 3000 m, ~20 min each, in 30-km diameter circles, starting ~1 hr before sunrise. (~3.5 hr) • 6-level vertical profiling in a 70-km long racetrack pattern starting in the FT (6000 m, 4000 m, and 2000 m, 20 min at each level) and then in the PBL (just below the PBL top, middle of the PBL, and 300 m, 30 min at each level) (~3 hr) • Late morning 150-km horizontal transect at 300 m, back to the airport (~0.5 hr)	**SOAS objectives**: direct quantification of VOC, ozone and NO_x surface fluxes and reconcile differences with "top-down" emission estimates; better understanding of HO_x/NO_x/ozone/organics/aerosol distributions, sources and sinks. **NAAMEX objectives**: Characterization of major Hg source region, examination of vertical profile of Hg^0 and Hg^{+2}. **TROPHONO objectives**: Examination of horizontal and vertical distributions of HONO, HNO_3, pNO_3 and NO_x in the continental background air masses; collection of bulk aerosol samples for photochemical experiments in the laboratory; examination of maximal HONO nighttime accumulation and its morning photolytic decay in the PBL and in the FT.
4. Ohio Valley transect and profiling , daytime, two 8.5-hr flights requested, early to late July	
• Morning transect from Tennessee to Ohio Valley at 3500 m, with some descents in BL enroute (~2 hr) • 6-level vertical profiling in Ohio Valley in a 70-km long racetrack pattern from lower PBL to 8000 m. (~3hr) • PBL profiling over Lake Michigan (~1.5 hr) • Afternoon transect from Ohio Valley to Tennessee at 3500 m (~2 hr)	**SOAS objectives**: direct quantification of VOC, ozone and NO_x surface fluxes and reconcile differences with "top-down" emission estimates; better understanding of HO_x/NO_x/ozone/organics/aerosol distributions, sources and sinks. **NAAMEX objectives**: Characterization of most concentrated Hg source region in North America, examination of vertical profile of Hg^0 and Hg^{+2}. **TROPHONO objectives**: Examination of horizontal and vertical distributions of HONO,

	HNO_3, pNO_3 and NO_x in the continental background air masses; collection of bulk aerosol samples for photochemical experiments in the laboratory; evaluation of relative HONO source strengths from photo-enhanced NO_x reaction on aerosol surface *vs* p-NO_3 photolysis in urban and industrial plumes.
5. Florida/Gulf of Mexico transect and profiling , daytime, two 8.5-hr flights requested, early to late July	
• Morning transect from Tennessee to South Florida at 3500 m with some descents in BL enroute (~2.5 hr) • 8-level vertical profiling over Gulf of Mexico (>300 km off South Florida shoreline) in a 70-km long racetrack pattern from lower MBL to 8000 m. (~3 hr) • Afternoon transect from Gulf of Mexico to Texas 8000 m (~1.5 hr) • Descent over Texas to 3000 m and return to Tennessee. (~2 hours)	**SOAS objectives**: Direct quantification of VOC, ozone and NOx surface fluxes and reconcile differences with "top-down" emission estimates; better understanding of HOx/NOx/ozone/organics/aerosol distributions, sources and sinks. **NAAMEX objectives**: Examination of vertical profile of Hg^0 and Hg^{+2} in region where models predict high Hg^{+2}. Examination of cloud scavenging of Hg^{+2} in Gulf of Mexico region. **TROPHONO objectives**: Examination of horizontal and vertical distributions of HONO, HNO_3, pNO_3 and NO_x in the continental and oceanic air masses; collection of bulk aerosol samples for photochemical experiments in the laboratory.
6. Florida/North Atlantic transect and profiling , daytime, two 9-hr flights requested, early to late July	
• Morning transect from Tennessee to South Florida at 3500 m with some descents in BL enroute (~2 hr) • 8-level vertical profiling over the North Atlantic (~300 km off North FL and GA coast) in a 70-km long racetrack pattern from lower MBL to 8000 m. (~3hr) • Off-coast transect from North FL to New York/New Jersey at 3500 m (~2 hr) • Descent into BL and return to TN (~2 hr)	**SOAS objectives**: Direct quantification of VOC, ozone and NOx surface fluxes and reconcile differences with "top-down" emission estimates; better understanding of HOx/NOx/ozone/organics/aerosol distributions, sources and sinks. **NAAMEX objectives**: Characterization of outflow from major Hg source region, examination of vertical profile of Hg^0 and Hg^{+2}, verification of model predicted gradients in Hg. **TROPHONO objectives**: Examination of horizontal and vertical distributions of HONO,

	HNO_3, pNO_3 and NO_x in the continental and oceanic air masses; collection of bulk aerosol samples for photochemical experiments in the laboratory.
7. Offshore outflow flight: daytime, two 9-hr flights requested, early to late July	
• Morning transect due east from Tennessee for 1100 km at 3000 meters over land, dropping to 1000 meters over the ocean (~3 hrs). • Proceed due north for 600 km, remaining at 1000 meters (~1.5 hrs) • Ascend to 3000 meters and trace route back to Tennessee. (~4.5 hrs)	**SOAS objectives:** N.A. **NAAMEX objectives**: Characterization of outflow from major Hg source region, examination of vertical profile of Hg^0 and Hg^{+2}, verification of model predicted gradients in Hg. **TROPHONO objectives**: Examination of distributions of HONO, HNO_3, pNO_3 and NO_x in the continental and oceanic air masses; Collection of bulk aerosol samples for photochemical experiments in the laboratory.

Table 2. Total flight hours requested

Flight type	Number of flights requested	Hours for each flight	Total hours for that flight type
1	8	8	64
2	1	7.5	7.5
3	1	7.5	7.5
4	2	8.5	17
5	2	8.5	17
6	2	9	18
7	2	9	18
Total research hours requested			149

This does not include ferry time from Colorado to Tennessee.

Schedule:

Our preferred time period is June 15-August 1, but this could be moved 2 weeks later with no major impacts to the project.

Table 3. NOMADSS C-130 Payload

Instrument	Lead	Location
RAF Mission Scientist Display	Webster	flight deck
RAF State Parameters	Schanot	Fuselage
RAF Fast Hygrometer	Beaton	Fuselage
RAF Fast Temperature	Schanot	Fuselage
RAF CDP Cloud Probe	Rogers	wing pod
RAF PCASP Aerosol Probe	Rogers	wing pod
RAF SPP-300 Aerosol Probe	Jensen	wing pod
RAF UHSAS Aerosol Probe	Rogers	wing pod
RAF King Probe Liquid Water	Schanot	wing
RAF OPHIR-III In Cloud Temperature	Beaton	wing pod
RAF Cloud Base Temperature	Schanot	Fuselage
RAF Radiometric Surface Temperature	Schanot	Fuselage
RAF Up/Down IR Irradiance	Haggerty	Fuselage
CARI NO-NO2	Weinheimer	cabin / HIMIL (1) inlet
CARI Fast Ozone	Campos	cabin / HIMIL (1) inlet
CARI Carbon Monoxide	Campos	cabin / HIMIL (1) inlet
CARI Picarro Carbon Dioxide	Flocke	cabin / HIMIL (1) inlet
EOL / HAIS GT-CIMS (2 units)	Huey	cabin / HIMIL (2) inlet
Whole Air Canister system for VOCs*	EOL	cabin / inlet
SOAS Specific Systems		
EOL / HAIS TOGA for about 25 hydrocarbons, 15 oxygenated VOC, 12 halocarbons	Apel	cabin / HIMIL (3) inlet
NCAR/ACD PTRMS for isoprene, MVK/MAC, total monoterpene and methanol fluxes during flight pattern 1 and a larger number of VOC (including acetonitrile, DMS, acetone, acetaldehyde, benezene, toluene, xylene) during other flights.	Karl	cabin / inlet
NAAMEX Specific Systems		
UW GEM/GOM Mercury	Jaffe	cabin /Special inlet (A)
CU HOx / H2SO4	Cantrell	cabin / Special inlet (B)
TROPHONO Specific Systems		
SUNY HONO / HNO3	Zhou	cabin / HIMIL (4) inlet
SUNY pNO3 / pOrganics	Zhou	cabin / SDI inlet
SUNY Bulk Aerosol	Zhou	cabin / SDI inlet
UCLA Mini – DOAS for NO_2, HONO, HCHO, BrO, IO, SO_2	Stutz	cabin / window
Up/Down Vis & UV Irradiance	Haggerty	Fuselage

Notes:
*EOL Canisters are highly desirable. Analysis could be done by Atlas (U. Miami), NCAR or NOAA. NOAA will deploy a GC in Nashville for canister analysis during SENEX and would like to use some of the EOL canisters and may be able to analyze some canisters from the C130.

All CARI Instruments share a common "HIMIL" inlet ala DC3 project.