INTEX-NA: Intercontinental Chemical Transport Experiment - North America

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ABSTRACT

INTEX-NA* (http://geo.arc.nasa.gov/sgg/singh/) is an integrated atmospheric field experiment to be performed over North America. It seeks to understand the transport and transformation of gases and aerosols on transcontinental/intercontinental scales and their impact on air quality and climate. A particular focus in this study is to quantify and characterize the inflow and outflow of pollution over North America. The main constituents of interest are ozone and precursors, aerosols and precursors, and the long-lived greenhouse gases. INTEX-NA is part of a larger international ITCT (Intercontinental Transport and Chemical Transformation) initiative (http://www.al.noaa.gov/WWWHD/pubdocs/ITCT/). INTEX-NA goals are greatly facilitated and enhanced by a number of concurrent and coordinated national and international field campaigns and satellite observations. Synthesis of the ensemble of observation from surface, airborne, and space platforms, with the help of a hierarchy of models is an important goal of INTEX-NA.

INTEX-NA is to be performed in two phases using the NASA DC-8 and P-3B as its principal platforms. Phase A will take place during the summer (June/July) of 2004 and Phase B during the spring (April/May) of 2006. Phase A is in summer when photochemistry is most intense and climatic issues involving aerosols and carbon cycle are most pressing, and Phase B is in spring when Asian transport to North America is at its peak. It is anticipated that approximately 170 flight hours for each of the aircraft (DC-8 and P-3B) will be required for each Phase. Several coastal and continental sites across North America have been selected as bases of operation. The experiment will be supported by forecasts from meteorological and chemical models, satellite observations, surface networks, and enhanced O_3-sonde releases.

To expand the temporal and spatial scale of airborne measurements and to maximize scientific output, INTEX-NA will be closely coordinated with field activities by several national and international partners. Interaction with ongoing satellites measurement programs (e. g. Terra, Aura, Envisat) is an important goal of INTEX-NA. This will involve in particular the validation of the satellite observations in order to provide a seamless data set for application to the INTEX objectives. NOAA is a principal US partner that is planning to field coordinated airborne and shipboard platforms. Plans are underway by United Kingdom, Germany, and France to launch concurrent airborne campaigns with a focus on the transport of pollution from North America to the eastern Atlantic and Europe. Japan is expected to be a major partner in Phase B. Results from INTEX-NA should directly benefit the development of environmental policy for air quality and climate change.

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* See Appendix 1 for explanation of Acronyms

I. INTRODUCTION AND OVERVIEW

A central component of NASA's grand vision in Earth Sciences is to understand how the Earth's atmosphere is changing and what are the consequences of this change? Some of the guiding Science Questions in this vision are:

- *What trends in atmospheric constituents and solar radiation are driving global climate?*
- *How is atmospheric ozone changing, as abundance of chemically active source gases increase?*
- *How do atmospheric trace constituents respond to changes in climate and atmospheric composition?*
- *What are the consequences of climate changes on regional air quality?*
- *How do ecosystems and biogeochemical cycles respond to and affect global environmental change?*
- *How well can future atmospheric chemical impacts on ozone and climate be predicted?*

A key requirement in addressing above questions is the availability of the necessary observational data. In recent years airborne experiments, complemented by satellite derived measurements, have been undertaken around the globe to develop these data sets along with the associated interpretive framework. These studies have been driven by two overarching goals:

(1) To improve our understanding of sources and sinks of environmentally important gases and aerosols through the constraints offered by atmospheric observations; and

(2) To understand the linkages between chemical source regions and the global atmosphere, and the implications for global human influence on climate and air quality

There is substantial evidence that gases and aerosols can be transported on intercontinental scales. Thus regional pollution can effect the global atmosphere and the resulting chemical and climate changes in turn can influence regional air quality. The difficulty in quantifying the chemical and radiative impacts of gases and aerosols, and the potential impact of intercontinental transport on air quality goals of individual countries, has led to the launching of a new IGBP/IGAC initiative, Intercontinental Transport and Chemical Transformation (ITCT). This international initiative emphasizes the need for an integrated observational strategy involving ground-based, aircraft, and satellite platforms, closely interfaced with global 3-D chemical tracer models [http://www.al.noaa.gov/WWWHD/pubdocs/ITCT/].

The Intercontinental Chemical Transport Experiment – North America (INTEX-NA) is an integrated field experiment directly targeted at the ITCT goals and at the Science Questions of the NASA Earth Science Enterprise. It will use aircraft observations, integrated with satellite data and a hierarchy of models, to address these questions. INTEX-NA will use two aircraft, the NASA DC-8 and P-3B, and will be conducted in two phases, phase A (summer 2004) and phase B (spring 2006). Concurrent airborne experiments by national and international partners and satellite measurements from Terra (MODIS, MISR, MOPITT), Envisat (SCIAMACHY, MIPAS), and Aura (TES, OMI) will greatly enhance the value of the INTEX-NA data set, and will be closely integrated into the observational strategy. This will involve in particular the validation of the satellite observations in order to provide a seamless data set for application to the INTEX-NA objectives.

II. SCIENTIFIC OBJECTIVES

INTEX-NA science objectives are directly targeted at the ITCT goals and at the Science Questions of the NASA Earth Science Enterprise. INTEX-NA will provide the observational database needed to quantify the inflow and outflow of environmentally relevant gases and aerosols over North America, and their transport and transformation on transcontinental and intercontinental scales. The constituents of primary interest are ozone and precursors (VOCs, NO_x, HO_x), aerosols and precursors, and long-lived greenhouse gases (CO_2, CH_4, N_2O). These constituents are important for their influence on climate change and air quality. The observational database will be obtained in two intensive airborne missions to be performed in the summer of 2004 (Phase A) and the spring of 2006 (Phase B) as well as a number of collaborative studies that will include airborne and satellite observations. The latter will provide additional measurements that expand the temporal and spatial scope of INTEX-NA observations. Synthesis of the ensemble of observations from surface, airborne, and space platforms with the help of hierarchy of regional/global models will be used to achieve the following main science objectives:

(1) Quantify the outflow of radiatively and chemically important trace gases and aerosols from North America to the Atlantic, and relate this outflow to our understanding of sources and sinks over North America and elsewhere;
(2) Understand the transport and chemical evolution of the North American outflow over the Atlantic, and assess the impact and implications of the intercontinental transport of pollution on the global atmosphere and on regional air quality and climate;
(3) Quantify the transpacific transport of Asian pollution to North America.and its implications for air quality.

INTEX-NA will also perform the following important supporting functions that address critical needs of the scientific community and greatly facilitate the achievement of its objectives:

- Utilize INTEX-NA airborne platforms and observational strategy to validate key satellite observations (e. g. H_2O, O_3, NO_2, NO, HNO_3, CO, CH_4 and HCN) in the troposphere especially from the Aura and Envisat platforms.
- Support NACP objective to quantify the North American carbon sink through direct observations of climatically relevant trace gases (e. g. CO_2 and methane)

and aerosols across North America from the eastern Pacific to the western Atlantic and beyond.

A critical task towards the achievement of INTEX-NA objectives will be inter-comparison of observations among multiple airborne platforms in order to generate a seamless data set. Other key tasks will include characterization of air masses entering the United States from its western, southern, and northern boundaries; and the comparison of measured chemical fields with those forecasted by regional/global models. Theories of photochemical ozone and aerosol production and loss in background and polluted air masses will be tested and the role of aerosols in heterogeneous chemistry and partitioning of key trace gases investigated.

III. A BRIEF DISCUSSION OF KEY SCIENCE OBJECTIVES

The achievement of the main science objectives requires an integrated observational strategy and a hierarchy of global/regional models. We elaborate here on the three INTEX-NA science objectives, providing some general background information for each and then focusing on the specific tasks for INTEX-NA.

Quantifying the chemical outflow from North America to the Atlantic: This objective addresses two levels of challenge: (1) better understanding of North American sources and sinks through the constraints afforded by chemical characterization of the outflow, (2) better understanding of the chemical processing in the continental boundary layer and its coupling to boundary layer ventilation.

Background. There is presently considerable interest in using atmospheric observations for top-down estimates of surface sources and sinks through inversion techniques. This interest is driven by the limitations of bottom-up approaches for constructing emission inventories. It is also driven by the rapid growth of atmospheric observations and the expected boost over the next decade from satellite instruments. Bottom-up approaches for constructing emission inventories (or, more generally, surface boundary conditions for atmospheric species) rely on local source characterization using observations and process models, followed by extrapolation to the globe on the basis of biogeochemical, economic, or sociological data. Top-down approaches use CTMs to construct a Jacobian matrix relating atmospheric concentrations to surface boundary conditions, and then apply atmospheric observations to retrieve the boundary conditions through inversion of the CTM. In practice, top-down approaches must use bottom-up source information as *a priori* information for the inversion. Formal inversion analyses derive an optimized emission inventory through the minimization of a cost function including information from both the *a priori* bottom-up knowledge and the constraints from the atmospheric observations, weighted by their respective errors in a Bayesian framework.

Such formal top-down inversions of global emissions have been done so far mainly for long-lived gases (CO2, CH4, CO, halocarbons, acetone). For these gases, the atmospheric concentrations can be related linearly to sources and the CTM representation of transport has some reliability but poor error characterization. For short-lived chemicals, CTM errors are greater and even more difficult to characterize. Multi-species invesions, which would be a logical approach to take advantage of error correlations between species with common sources, have not been attempted so far because of lack of information on error covariance. Often there are significant differences between top-down and bottom-up estimates. One of the most important issues has been the large discrepancy between bottom-up estimates of the North American carbon sink (<1 PgC/yr) and what is inferred from top down approaches (2-3 PgC/yr).

Aircraft campaigns focused on the continental boundary layer and continental outflow hold the key for better characterization and reduction of the errors involved in top-down estimates of emissions. They can achieve this through (1) measurements of a large ensemble of species with high accuracy and spatial resolution over a range of conditions simulated by the CTMs, (2) specific investigation of processes contributing to the errors (e.g., radical chemistry, boundary layer ventilation), (3) measurements of correlations between species as constraints on their sources. This critical role for aircraft campaigns is in addition to the intrinsic value of the data collected for constraining top-down estimates, and complements in a unique way the data that could be collected through long-term atmospheric monitoring from satellites, surface sites, or regular aircraft flights.

Continental boundary layer processing and coupling to the free troposphere is critical for understanding the outflow of short-lived gases and aerosols from continental source regions and their impact on the global atmosphere. For example, the fraction of emitted reactive nitrogen oxides and aerosols that is exported from the U.S. boundary layer is known to be small but is highly uncertain; and it is this small and uncertain fraction that determines U.S. influence on the global budgets of tropospheric ozone and aerosols. Specific and poorly understood issues involved in the export of these short-lived species include nonlinear chemistry; aerosol nucleation, growth, and scavenging; and the mechanisms for boundary layer ventilation.

Task for INTEX-NA**.** INTEX-NA provides an outstanding opportunity to test our ability to relate atmospheric observations in the continental boundary layer and in continental outflow to our *a priori* knowledge of continental sources, and this for a region of major global environmental relevance. Emission inventories for North America are of higher quality than elsewhere and an intensive network of meteorological observations reduces the errors in modeling transport. An intensive network of ground-based observations is available through both air quality agencies and research groups. A number of previous aircraft missions (NARE, ITCT-2K2, ABLE-3, SOS, and others) have provided important information on continental boundary layer chemistry and North American outflow. INTEX-NA will be able to sample both the continental boundary layer and the North American outflow, providing a range of constraints. It will benefit from a greater range of satellite coverage than available for previous missions. Finally, phase A will operate concurrently with other aircraft missions focused on North American chemical transport and outflow (ITCT-2K4, COBRA) that will provide complementary coverage and constraints.

INTEX-NA will provide information for improved top-down estimates of North American sources through surveys of the continental boundary layer and the continental outflow as well as through focused studies of boundary layer ventilation and chemical evolution. Boundary layer observations are expected to be most useful for inversion of sources because transport errors are relatively small. Emphasis will be on large-scale regional source characterization (100-1000 km) rather than on local pollution plumes, in order to make optimal use of the capabilities of the INTEX-NA aircraft. Large-scale plumes from fires in the western United States of Canada will represent targets of opportunity. Meteorological and CTM chemical forecasts will be used in the field to optimize the flight tracks for the characterization of regional outflow. Post-mission analysis will involve integration of the INTEX aircraft observations with observations from other aircraft missions, and from satellites, to optimize the top-down constraints on North American sources.

Quantifying the export efficiencies of short-lived species out of the continental boundary layer will be an important task for INTEX-NA. These efficiencies depend on chemical and aerosol processing within the boundary layer, precipitation scavenging of soluble species, and coupling of the ensemble of these processes with ventilation of the boundary layer. Quantitative analysis of these export efficiencies will require characterization of radical chemistry and aerosol evolution within the continental boundary layer, for air masses with a range of source signatures and chemical histories. Lagrangian sampling of aging air masses would be ideal to achieve but may not be practical except in specific cases (e.g., plumes from wild fires) because of the disperse nature of sources. Chemical indicators such as NO_x/NO_y or hydrocarbon ratios have been successfully used for chemical aging of air masses.

The two phases of INTEX-NA (summer and early spring) will allow investigation of the seasonal variation in the surface fluxes of important biogenic species such as CO_2, CH_4, and oxygenated organic compounds. As stated earlier, the summer phase will be conducted at a time when vegetation is most active and the spring phase will be conducted at a time when the vegetation is dormant in much of the continent. Comparison of the data between the two phases will be of considerable value for quantifying the biogenic terms in the North American budgets and to determine biogenic influences in the North American outflow.

Understanding the chemical evolution of North American outflow over the Atlantic: This objective is focused on the short-lived constituents (such as ozone and aerosols) and involves two issues: (1) linkage between North American outflow and the global atmosphere, and (2) transatlantic transport of pollution.

Background**.** Chemical outflow of ozone and aerosols from North America has important implications for climate and global atmospheric chemistry that depend on their further evolution downwind of the continent. Addressing the ultimate fate of these species is a major challenge for global tropospheric chemistry. Of particular interest is the evolution in the near-field outflow, where relatively high concentrations lead to active chemistry and where superimposition of different influences associated with continental outflow (anthropogenic pollution, natural continental sources, lightning, stratospheric intrusions) can introduce significant complications. There is little confidence at present in the ability of global CTMs to describe this near-field evolution. Large seasonal variations can be expected in this evolution but again the uncertainties are large.

Transatlantic transport of pollution is a related but separate issue. European countries, through the Long-Range Transport of Atmospheric Pollutants (LRTAP) protocol, have argued for some time that emission reductions in the United States were needed for Europe to meet its ozone and aerosol air quality objectives. Recent model studies suggest that transatlantic transport of North American pollution may indeed cause enhancements of ozone in surface air over Europe, and there has been observational evidence for transport of Canadian fire plumes to the Mace Head observing station in Ireland. Part of the transatlantic transport is thought to take place directly in the boundary layer, with the remainder taking place in the free troposphere followed by subsidence. The transport is thought to be maximum in winter-spring, but it also significant in summer when the application to air quality is most relevant. The magnitude of the effect remains highly uncertain and the implications for policy are considerable. Critical to improving our understanding is the characterization of the dispersion and chemical evolution of North American pollution plumes as they travel across the North Atlantic.

Task for INTEX**.** Characterizing the near-field evolution of North American outflow over the western North Atlantic and in the free troposphere over North America will be a top priority for INTEX, both in Phase A (summer) and Phase B (spring). It will take advantage of the long-range capabilities of the NASA DC-8 aircraft, its extensive chemical payload, and the relatively good characterization of the meteorological environment. Cold fronts (with associated warm conveyor belts) and deep convection provide the main pathways for outflow from North America to the North Atlantic. We expect that INTEX will be able to follow the chemical evolution of these systems for several days as they are transported to the North Atlantic.

Investigation of the transatlantic transport of ozone and aerosol pollution will be done during phase A in partnership with European aircraft missions conducted concurrently with INTEX. These missions involve groups from the U.K. (ITOP), France (CNES), and Germany. They will be based in western Europe or the eastern North Atlantic, and focus on different aspects of the chemical aging of North American outflow and the intercontinental transport of pollution. Close coordination will be achieved with these missions to provide a complete history of chemical aging and dispersion of North American pollution during transatlantic transport.

Quantifying the transpacific transport of Asian pollution to the United States and the implications for U.S. air quality: This objective is focused on the intercontinental transport of pollution**,** a primary ITCT objective.

Background**.** There is increasing concern that efforts to improve air quality in the United States through domestic emission controls could be thwarted by Asian industrialization and the associated transpacific transport of pollution. This transport is initiated by cold frontal passages over eastern Asia, which lift continental boundary layer air to the free troposphere where it is then carried towards North America by the westerlies. Subsidence of this Asian air over North America then takes place behind cold fronts. Transpacific transport is most frequent and rapid in spring, when frontal activity is maximum and the atmospheric circulation is strong. It is minimal in summer when much of the ventilation of eastern Asia is to the upper troposphere (monsoon) and when the westerlies are shifted to the north.

Dramatic evidence for transpacific transport of Asian air to North America during spring is offered by Asian dust plumes, which have been tracked by satellite across the ocean and found to cause large-scale exceedances of air quality standards at sites in the western United States. Asian pollution plumes (diagnosed by elevated CO and aerosols) have also been observed from aircraft and at ground sites along the west coast. The ITCT-2K2 aircraft mission in spring 2002 out of Monterey provided detailed chemical characterization of two Asian pollution plumes. Model studies have suggested that an enhancement of several ppbv in surface ozone in spring could be expected due to the transpacific transport of Asian pollution. However, there is still considerable uncertainty as to the importance of this transpacific transport and its relevance for surface air quality in the United States.

Task for INTEX-NA**.** Characterization of the transpacific transport of Asian pollution will be a major focus of the Phase B of INTEX-NE (spring 2006). A critical element in this focus will be the close partnership with satellite observations (e.g., from MODIS, TES, SCIAMACHY) tracking Asian plumes of CO and aerosols across the Pacific. The aircraft will intercept the plumes observed from satellite and provide detailed information on their chemical composition and evolution. Operations out of Hawaii as well as along the West Coast will allow a near-complete tracking of the chemical aging and aerosol processing of the plumes as they are advected across the Pacific. These observations will then be interpreted with CTMs to relate them to the Asian sources and to assess the quality of our understanding of the transpacific transport of pollution.

Subsidence of Asian air to the United States will also receive particular attention during Phase B of INTEX-NA, building on the exploratory results obtained by the ITCT-2K2 campaign out of Monterey. Asian plumes will be tracked as they travel across the United States and are entrained into the boundary layer. The relative importance of cold fronts and continental downwelling will be examined. CTM forecasts during ITCT-2K2 indicated frequent occurrences of blocking Highs over the central Pacific, deflecting Asian air masses towards Canada from which they flowed southward to the NW United States; the importance of this process will be examined. The information obtained from INTEX-NA will allow us to quantify the present-day Asian influence on U.S. air quality, in a season where this influence is maximum, and to test models being used to forecast how this influence may grow in the future.

IV. INTEX-NA Mission Plan

INTEX-NA will use two aircraft, the NASA DC-8 and P-3B, and will be conducted in two phases, phase A (summer 2004) and phase B (spring 2006). Phase A is in summer when photochemistry is most intense, biogenic sources and carbon sinks are most active, and climatic issues involving aerosols and carbon cycle are most pressing. Phase B is in spring when Asian transport to North America is at its peak and vegetation is dormant in much of the continent. Primary focus will be on the eastern United States and the Atlantic in phase A and the western United States and the Pacific in Phase B.

A. General considerations and linkages

INTEX-NA mission plan will emphasize coordination between aircraft measurements, satellite observations, and models in the pursuit of the mission objectives. The strategy will build on the previous experience from a number of missions such as Trace-P, Ace-Asia, and Indoex,. Mission design and day-to-day flight operations will be guided by forecasts from a hierarchy of global and mesoscale moderls. Near-real-time observations from a number of satellite instruments will also be used to guide the execution of the mission and to identify specific regions of interest for in-situ sampling. Integration of aircraft and satellite measurements to address the mission objectives will require validation flights directed at establishing the consistency between the two data sets. A key element in INTEX-NA planning and execution will be the linkage with several other aircraft missions that are to be conducted concurrently. Table 1 summarizes the various missions and activities that are planned during the summer-2004 INTEX-NA campaign. These missions and activities both enhance and facilitate the achievement of INTEX-NA objectives. Collaborations with partner missions will be pursued actively. Modes of collaboration will include exchange of forecasted fields, coordinated flights, in-flight intercomparisons, common data-sharing protocols, and joint Science Team meetings.

Table 1: INTEX-NA/Phase A linkages during the Summer-2004 mission*

Mission type	Mission/deployment date	Platforms (max altitude coverage)	Base of operation	Salient goals and connections with INTEX-NA
Airborne**	ITCT-2k4/US Summer-2004	P-3 (7 km)	Northeastern, US (Pease AFB, NH)	Outflow and evolution of pollution from NA. Objectives focus on air quality and climate studies and are similar to INTEX-NA
	ITOP/U.K. Summer-2004	BAe-146 (10 km)	Mid Atlantic (Azores)	Transport and evolution of NA pollution across the central/eastern Atlantic. Complements and adds to the intercontinental aspects of INTEX-NA. Offers opportunities for quasi-lagrangian studies
	DLR/Germany Summer-2004	Falcon-20 (13 km)	Continental Europe (Shannon, Ireland; Prestwick, Scotland)	Transport of NA pollution to eastern Atlantic & western Europe. Complements and adds to the intercontinental aspects of INTEX-NA. Offers opportunities for quasi-lagrangian studies & satellite validation.
	COBRA-NACP/US Spring/Summer 2004	King Air (6 km)	Eastern & northeastern US	Carbon fluxes on a regional scales. INTEX-NA will support COBRA and provide large scale surveys of CO_2, CO, CH_4, aerosol, and tracers. NACP is developing plans for intensive missions over eastern US.
	Service d'Aéronomie /France Summer-2004	Mystere-20 (10 km)	Continental Europe	Transport of NA pollution to eastern Atlantic & western Europe.
Satellite	Aura-Terra/US; Envisat/EU	Satellite (troposphere & stratosphere; 50 km)	Space based/global	Global monitoring on multi-year time scales. Greatly enhances temporal & spatial relevance of INTEX-NA observations. Some key instruments are MOPITT, TES, OMI, and SCIAMACHY. INTEX-NA will provide validation data in the troposphere.
Surface	ITCT-2k4/US Summer-2004	NOAA research ship RV-Ron Brown	Western Atlantic	Marine BL gases and aerosols and air/sea exchange processes. Provides measurements complementary to INTEX-NA
	Ozonesondes releases (multi-year)	Sondes (troposphere & stratosphere; 50 km)	Across NA and Atlantic	Long-term characterization of O_3 and H_2O over NA & Atlantic. Enhances temporal and spatial relevance of INTEX-NA observations

* Spring-2006 experiment (INTEX-NA/Phase B) will also include Asian partners including Japan
** Depending on the size of the platform, these missions will have in-situ and remote sensing capability similar/complementary to INTEX-NA.

B. Measurement priorities and payload

The DC-8 and the P-3B aircraft will be equipped with a comprehensive suite of in-situ and remote sensing instrumentation to provide chemical, physical, and optical measurements during INTEX-NA. Priority measurements will include long-lived greenhouse gases, ozone and its precursors, aerosols and their precursors, radicals and their reservoirs, chemical tracers of sources and transport, as well as several optical parameters. These priority measurements are listed in Table 2. Measurements of chemical radicals and aerosol microphysics will be of particular importance aboard the P-3B as they are critical for analysis of chemical processing and aerosol evolution in the continental boundary layer. Measurements of chemical tracers of air masses will be of particular importance aboard the DC-8 for the interpretation of aged North American outflow. Each measurement is rated with a priority scale of 1 to 5: Priority 1- Mission critical; Priority 2- Very important; Priority 3- Important; Priority 4- Useful; Priority 5- Exploratory. Priority 1 measurements are of highest importance and a failure of one of these measurements prior to the mission or in the field could alter mission plans. It is expected that the aircraft will include all measurements of priority 1 and 2 plus some measurements of Priority 3. Priority 3 (and 4) measurements will be favored when they are add-ons to Priority 1 and 2. Priority 5 measurements are desirable but may not yet be technically ready for airborne operation. Because innovation is critical, it is expected that at least one such exploratory instrument will be included in the payload. Table 2 also shows the desired minimum instrument detection limits and time resolutions for INTEX-NA. Performance beyond these minimum requirements in terms of speed, precision, accuracy, and specificity is desired and will be an important consideration in the selection of the aircraft payload. The size and weight of instrumentation is also an important consideration.

A nation-wide network of four stations that launch weekly ozonesondes already exists: Trinidad Head, CA (41.1˚N, 124.2˚W); Boulder, CO (40.0˚N, 105.3˚W); Huntsville, Al (34.7˚N, 86.6˚W); and Wallops Island, VA (37.9˚N, 75.5˚W). During a 3-month period overlapping the INTEX-NA intensives the frequency of releases at these stations will be augmented to one per day. It is expected that ozonesonde releases will also occur at 2 to 3 additional sites to coincide with INTEX-NA intensives. Sites in southern Texas, Azores, and Iceland are best suited for this purpose (Figure 1). Weekly ozonesonde releases also take place from several Canadian sites (Edmonton-54˚N, 113˚W; Churchill-59˚N, 90˚W; Goose Bay-53˚N, 61˚W).

Table 2: INTEX-NA payload and nominal measurement requirements for DC-8 and P-3B

Species/parameters	Priority DC-8*	Priority P3-B*	Detection limit	Nominal Resolution#
In-situ measurements				
O_3	1	1	3 ppb	1 s
H_2O	1	1	10 ppm (±10%)	5 s
CO_2	1	1	0.5 ppm	5 s
CO	1	1	3 ppb	5 s
CH_4	2	2	10 ppb	5 s
N_2O	2	2	1 ppb	10 s
NO	1	1	5 ppt	5 s
NO_2	2	2	10 ppt	1 min
HNO_3	2	2	30 ppt	2 min
PAN/PPN	2	2	5 ppt	5 min
H_2O_2	2	2	50 ppt	5 min
CH_3OOH	2	2	50 ppt	5 min
HCHO	2	2	50 ppt	1 min
$OH/HO_2/RO_2$	2	2	0.01/0.1/0.2 ppt	1 min
SO_2	2	2	10 ppt	1 min
Speciated NMHC	2	2	5 ppt	5 min
Halocarbons	2	2	1-5 ppt	5 min
Aldehydes (>C_1) and ketones (oxygenates)	2	2	5-20 ppt	5 min
Aerosol size	2	2	10 nm-20 μm	1 min
Ultra fine/fine aerosol (CN)	2	2	D>3 nm	10 s
Black carbon/light absorbing aerosol	2	2	100 ng/SCM	5 min
Aerosol composition (organic & inorganic)	2	2	20 ppt	10 min
Extinction/scattering	3	3	--	1 s
Organic nitrates	3	3	5 ppt	5 min
Alcohols	3	3	20 ppt	5 min
Organic acids	3	3	20 ppt	5 min
Sulfuric acid	3	3	0.01 ppt	5 min
NO_y	3	3	30 ppt	10 s
HCN/RCN	3	4	20 ppt	5 min
Radionuclide (^{22}Rn, ^{7}Be, ^{210}Pb)	3	4	0.05-1 Bq/SCM	10 min
OCS	4	4	5 ppt	5 min
Single particle composition	4	4	D>50 nm	1 s
Remote measurements				
O_3 (nadir/zenith)	1	2	5 ppb	Z<500 m
Aerosol (nadir/zenith)	1	2	SR 1 at 1 μm	Z<100 m
Spectral/flux	2	2	10^{-5}/s (j_{uv})	10 s

radiometers/optical depth				
H_2O (nadir/zenith)	3	4	20 ppm	Z<500 m
Temperature	4	4	2 K	Z<500 m
Exploratory measurements				
NH_3	5-2	5-2	30 ppt	2 min
CO Lidar	5-2	5-2	20 ppb	Z<500 m
HNO_4	5-2	5-4	5 ppt	2 min
Real time NMHC/tracers	5-3	5-3	20 ppt	30 s
HNO_2	5-3	5-3	5 ppt	5 min
Meteorological/other measurements				
Meteorological Measurement System (u, v, w, T)	1	1	0.1%	1 s
Lightning/storm scope	3	3	NA	400 km range

*Priority 1: Mission critical; Priority 2: Very important; Priority 3: Important; Priority 4: Useful; Priority 5: Exploratory. Exploratory instrumentation is further ranked according to its desirability.
[#] Superior resolution than noted here is highly desirable.

C. Measurement strategy and deployment sites

INTEX will use two aircraft, the NASA DC-8 (ceiling 12 km, endurance 10 hours, nominal speed 400 kts) and the P-3B (ceiling 7 km, endurance 8 hours, nominal speed 300 kts). The DC-8 is the platform of choice for the task of large-scale chemical characterization and the P3-B is best suited for lower tropospheric and boundary layer studies including processes of exchange with the free troposphere. Both aircraft will pursue targeted objectives with optimized observational priorities. Major types of flights to be conducted will include:

(1) Inter-comparison flights among multiple platforms. This will involve formation flights to test and validate independent measurements on multiple airborne platforms. Flights over ships and fixed monitoring sites may also be performed as appropriate. This is a necessary and critical step towards developing a unified data set that can be seamlessly integrated and analyzed. This need is particularly acute for carbon cycle studies requiring ultra-high precision (e. g. ±0.1% for CO_2).

(2) Large-scale characterization of the troposphere across North America (DC-8 and P-3B). This will involve characterization of the troposphere (0-12 km) over the eastern Pacific, continental North America, western Atlantic, and possibly eastern Atlantic via European partners. The aim will be to define boundary conditions for inflow into North America and its development over the continent and over Atlantic. This is especially important for NACP goal to quantify the carbon sink over North America and for 3-D models that seek to develop a North American chemical budget.

(3) Characterization of continental boundary layer chemistry and venting (P-3B). This will involve large-scale transects of the continental boundary layer over source regions to characterize sources and chemical evolution, and vertical profiling between the boundary layer and the free troposphere to determine outflow mechanisms and the coupling between chemistry and transport. It will also involve (Phase A) flights over the central United States to define boundary conditions for the continental outflow to the North Atlantic, and flights of opportunity to sample western U.S. and Canadian fires.

(4) Large-scale continental outflow characterization (DC-8 and P-3B). This will involve large-scale transects over the North Atlantic, parallel to the East Coast, to characterize the ventilation of different source regions and through different pathways.

(5) Chemical aging over North Atlantic (DC-8, Phase A). This will involve sampling of North American outflow over the North Atlantic on successive days to track their chemical evolution. Under suitable conditions, attempts will be made to perform quasi-lagrangian studies in which air masses sampled over the western Atlantic are intercepted and sampled by European partners over the eastern Atlantic after several days. Similar studies are also anticipated over eastern US by coordinated sampling between the P3-B and the DC-8.

(6) Convective venting to the upper troposphere (P-3B and DC-8). This will involve vertical profiling of convective systems from the inflow region in the lower troposphere (P-3B) to the outflow region in the upper troposphere (DC-8). Comparison of the chemical and aerosol signatures in the inflow and outflow will be used to derive export efficiencies, in particular for soluble species that may be scavenged in the convective updraft.

(7) Transpacific transport of Asian pollution plumes (DC-8, Phase B). This will involve the interception of Asian pollution plumes during travel across the Pacific and the characterization of their chemical aging and layered structure. Activities over the western and mid-Pacific are anticipated in collaboration with Asian partners.

(8) Satellite validation flights (DC-8). INTEX-NA payload will be able to validate all Priority 1 and 2 measurements of the Aura platform in the troposphere. Salient among these are H_2O, O_3, NO_2, NO, HNO_3, CO, CH_4 and HCN. Validation will involve vertical profiling from the boundary layer to the aircraft ceiling (12 km) at the precise locations and times of satellite overpass, as was previously done for MOPITT validation in TRACE-P. In consultation with Aura investigators, additional flight profiles will be developed to benefit limb-scanning satellite instruments.

All instrument integration and testing for the DC-8 will take place at the Dryden Flight Research Center in southern California. Similarly P3-B instrument integration and test flights will take place from the Wallops Flight Facility in Virginia. Figure 1 shows operational sites for INTEX-NA and gives nominal flight tracks for Phase A for the DC-8 and the P-3B. Table 3 provides a summary of the nominal flight plans, flight hour allocations, and achievable objectives. These coastal and continental sites are chosen because they can support large missions and are well suited for INTEX-NA objectives. The eastern sites will enable the sampling of North American outflow to the Atlantic at all latitudes. The NE site (Bangor MN, or Pease AFB, NH) will further enable joint complementary operations with the ITCT-2K4 WP-3 campaign. The Wallops site for the P-3B will allow easy access to source regions of the eastern United States. The central US site (St. Louis, MO or equivalent) will allow for transects across the eastern United States, flights to the Gulf Coast and to the industrial midwest (major source regions), flights of opportunity to sample fire plumes, and definition of western boundary conditions for the domain of interest. Overnight "suitcase" flights will be conducted by the DC-8 to provide transcontinental cross-sections (Seattle) and if appropriate to track plumes from large Canadian fires. The deployment of aircraft will allow the characterization of North American outflow as it shifts from the easterly to northeasterly direction as the summer advances.

Tentative plans for Phase B of INTEX call for greater emphasis on the west coast and the western United States. It is expected that Asian partners will conduct concurrent mission over the western Pacific. We envision an operational site for the DC-8 in the central Pacific (e. g. Hawaii) to follow the chemical evolution of Asian plumes during their transport across the Pacific. Further definition of deployment sites for Phase B will be done following the execution of Phase A.

Final flight planning will be guided in the field with the benefit of satellite imagery, forecasted chemical fields, and weather conditions in a manner similar to previous missions. Remote sensing measurements (e. g. O_3, aerosol) and up to date satellite information will be used to make in-flight adjustments. Effective coordination with Air Traffic Control (ATC) is a critical part of airborne operation over North America and Atlantic and will require careful and early planning.

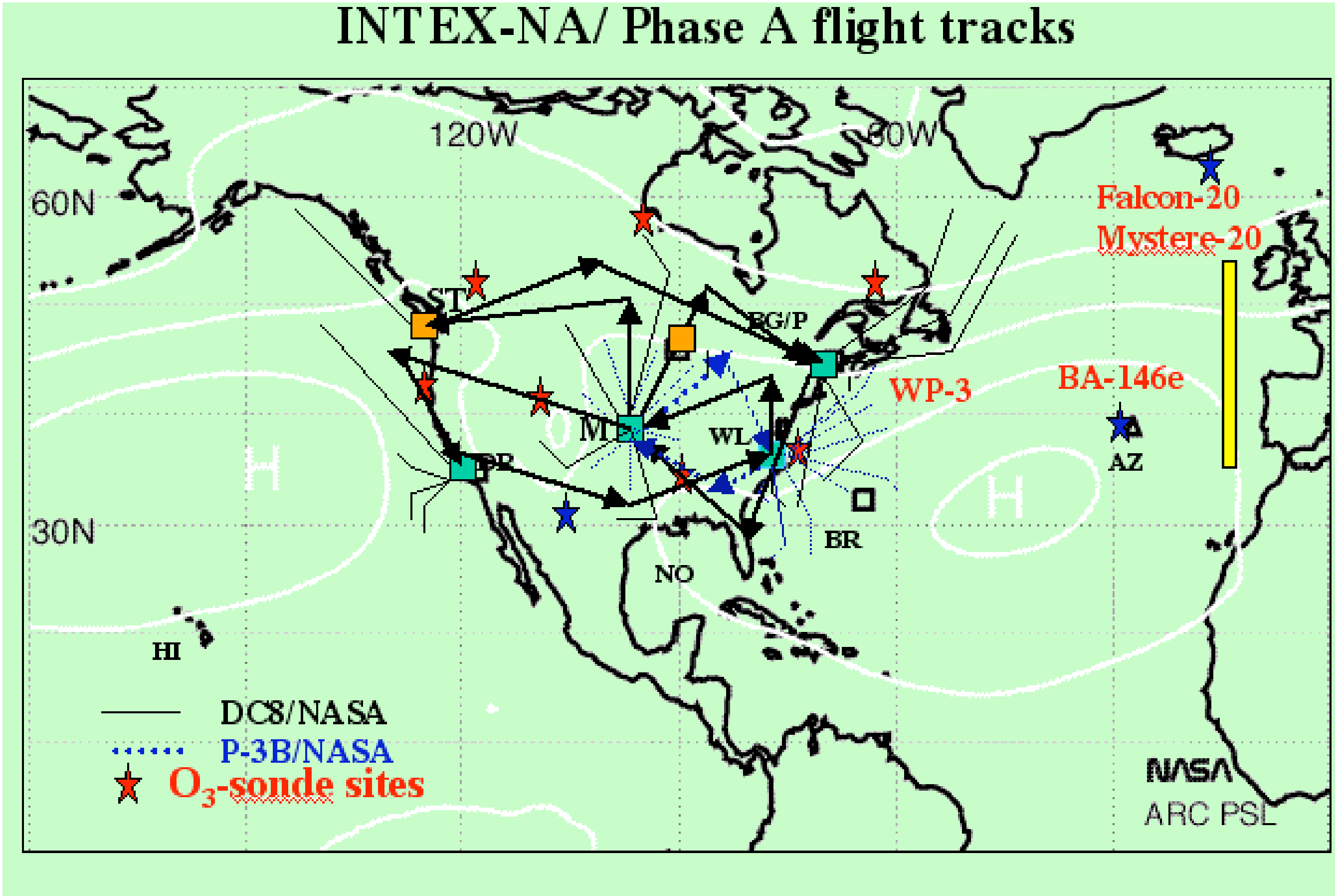

Figure 1: Nominal INTEX-NA flight tracks for Phase A (summer 2004). DC-8 tracks are shown in solid black lines while P3-B tracks are in dashed blue lines. Red stars in the top panel show existing ozonesonde stations. Blue stars indicate possible augmentations. Green squares represent main operational sites; amber color squares are for overnight operation. WP-3, BA-146, Falcon-20, and Mystere-20 are aircraft from NOAA (US), United Kingdom, Germany, and France, respectively. See Table 3 for location symbols and flight sequence.

Table 3: Operational sites, flight hour allocation, and main objectives for INTEX-NA/Phase A

DC-8 Flights				P3-B Flights			
Type*	No.	Flight Hours	Potential Objectives#	Type*	No.	Flight Hours	Potential Objectives#
Test flights-DR	3	13		Test flight-WL	3	13	
Missions-DR	1	9	7,8	Mission-WL	2	16	1,3,4
Transit to WL	1	9	1,2,6,8	Transit to M	1	8	2,3,6
Transit to M	1	9	2,6,8	Missions-M	4	32	1,2,3,6
Missions-M	4	35	1,2,6,8	Transit to WL	1	8	2,3,6
Transit to ST	1	8	2,6,8	Mission-WL	5	40	1,3,4
Mission- ST	1	9	7,8	Transit to M	1	8	2,3,6
Transit to BG	1	9	2,6,8	Mission-M	3	24	2,3,6
Missions-BG	5	43	1,4,5,6,8	Transit to WL	1	8	2,3,6
Transit to M	1	8	1,2,6,8				
Mission-M	1	9	1,2,6,8				
Transit to DR	1	9	2,6,8				
Total	**21**	**170**		**Total**	**21**	**157**	

*DR-Dryden Flight Research Center, CA; BG-Bangor, ME (or equivalent); ST-Seattle, WA; WL-Wallops Flight Facility, VA, M- mid-continental site (St. Louis, MO or equivalent)

#Brief description of objectives (see section IV C for details): 1-Intercomparison, 2-Transcontinental characterization, 3-BL characterization and exchange with FT, 4-N. American outflow to Atlantic, 5-Aging of N. American outflow, 6-Convective influence, 7-Inflow from Pacific, 8-Satellite under-flight

APPENDIX 1: Relevant acronyms

ATC: Air Traffic Control
CTM: Chemical Transport Model
IGAC: International Global Atmospheric Chemistry
IGBP: International Geosphere-Biosphere Program
INTEX-NA: Intercontinental Chemical Transport Experiment-North America
ITCT: Intercontinental Transport and Chemical Transformation
ITOP: Intercontinental Transport of Pollution
MIPAS: Michelson Interferometer for Passive Atmospheric Sounding
MOPITT: Measurement of Pollution in the Troposphere
MODIS: Moderate Resolution Imaging Spectroradiometer
NACP: North American Carbon Program
NOAA: National Oceanic and Atmospheric Administration
OMI: Ozone Monitoring Instrument
PEM: Pacific Exploratory Mission
SCIAMACHY: Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
SONEX: SASS Ozone and NO_X Experiment
TES: Tropospheric Emission Spectrometer
TRACE: Transport and Chemistry Experiment