INTEX-NA: Intercontinental Chemical Transport Experiment - North America

H. Singh[1], D. Jacob[2], and L. Pfister[1]

[1]NASA Ames Research Center, Moffett Field, CA 94035; [2]Harvard University, Cambridge, MA 02138

Steering committee (alphabetically):

United States: E. Browell, W. Brune, A. Clarke, J. Crawford, D. Davis, F. Fehsenfeld, D. Jacob, J. Logan, R. Newell, L. Pfister, V. Ramanathan, B. Ridley, M. Schoeberl, H. Singh, A. Tabazadeh, P. Tans, A. Thompson, C. Trepte, P. Wennberg

Europe: G. Brasseur, J. Lelieveld, S. Penkett, U. Schumann

Asia: H. Akimoto, Y. Kondo, S. Liu, T. Ogawa

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ABSTRACT

INTEX-NA* is an integrated atmospheric chemistry field experiment to be performed over North America using the NASA DC-8 and P-3B aircraft as its primary platforms. It seeks to understand the exchange of chemicals and aerosols between continents and the global troposphere. The constituents of interest are ozone and its precursors (hydrocarbons, NO_x and HO_x), aerosols, and the major greenhouse gases (CO_2, CH_4, N_2O). INTEX-NA will provide the observational database needed to quantify inflow, outflow, and transformations of chemicals over North America. INTEX-NA is to be performed in two phases. Phase A will take place during the period of May-August

2004 and Phase B during March-June 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. INTEX-NA will coordinate its activities with concurrent measurement programs including satellites (e. g. Terra, Aura, Envisat), field activities undertaken by the North American Carbon Program (NACP), and other U. S. and international partners. However, it is being designed as a "stand alone" mission such that its successful execution is not contingent on other programs. Synthesis of the ensemble of observation from surface, airborne, and space platforms, with the help of global/regional models is an important goal of INTEX-NA.

It is anticipated that approximately 175 flight hours for each of the aircraft (DC-8 and P-3B) will be required for each Phase. Principal operational sites are tentatively selected to be Bangor, ME; Wallops Island, VA; Seattle, WA; Rhinelander, WI; Lancaster, CA; and New Orleans, LA. These coastal and continental sites can support large missions and are suitable for INTEX-NA objectives. The experiment will be supported by forecasts from meteorological and chemical models, satellite observations, surface networks, and enhanced O_3-sonde releases. In addition to characterizing Atlantic-outflow and Pacific-inflow, INTEX-NA will characterize air masses transported between the U. S., Canada, and Mexico.

INTEX-NA will be the first continental scale inflow, outflow, and transformation experiment to be performed over North America. It will provide the most comprehensive observational data set to date to understand the $O_3/NO_x/HO_x$/aerosol photochemical system and the carbon cycle. One of the critical needs of the carbon cycle research is to obtain large-scale vertical and horizontal concentration gradients of CO_2 throughout the troposphere over continental source/sink regions. INTEX-NA is ideally suited to perform this role. Coastal and continental operational sites will allow us to develop a curtain profile of greenhouse gases (e. g. CO_2) and other key pollutants across North America. Such information is central to our quantitative understanding of chemical budgets on the continental scale. We expect to provide a number of satellite under-flights over land and water to test and validate observations from the appropriate satellite platform (e. g. Aura). We plan to develop strong collaborations with other national and international observational programs. 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

The primary goals of the NASA Global Tropospheric Experiment (GTE) are driven by NASA's strategic vision for Earth Sciences and aim to address the following overarching questions:

- How do changing emissions resulting from natural and man-made activities alter the composition of the atmosphere?
- How does the chemistry of the atmosphere respond to and affect changes in climate and air quality?
- What are the effects of regional pollution on the global atmosphere, and the effects of global chemical and climatic changes on regional air quality?
- How can we understand, model, and predict future change?

GTE has undertaken a long series of aircraft missions aimed at addressing these key questions (McNeal et al., 1998, http://www-gte.larc.nasa.gov). These air chemistry campaigns have been conducted in many regions of the globe (Arctic, Amazonia, southern Atlantic, Pacific) with a recent focus on the outflow of pollution from Asia to the Pacific (PEM West-B, TRACE-P). INTEX-NA is the next experiment in this series and focuses on North America. It also encompasses the spirit of the "integrated mission" concept (http://hyperion.gsfc.nasa.gov/Personnel/people/Kawa,_Randy/) in which synthesis of the ensemble of observation from surface, airborne, and space platforms is a major goal.

There is substantial evidence that pollution (gases and aerosols) from continents can travel over thousands of miles and impact air quality on intercontinental scales (Bertsen et al., 1999; Jacob et al., 1999; Stohl and Trickl, 1999; Yienger et al., 2001; Wild and Akimoto, 2001). There is further recognition that aerosols can impact gas phase chemistry in significant ways (Dentener et al., 1996). A new international initiative that focuses on the intercontinental transport and transformation of chemicals is currently being planned under the auspices of IGAC (ITCT, 2001). North America thus receives pollution from Asia and exports its pollutants to the troposphere and downwind continents. Our quantitative knowledge of the export fluxes of gases and aerosols from continents to the global atmosphere is poor. There is a clear need, from a policy and societal perspective, to quantify these exports to the global atmosphere and to assess their impact on global/regional air quality and climate.

INTEX-NA is an integrated field mission intended to provide the observational database needed to quantify the inflow and outflow of trace constituents over North America. It builds on the heritage of previous GTE missions and takes full advantage of the ensemble of unique capabilities in measurements, models, and platforms that have become available in recent years. The constituents of most interest are ozone and its precursors (hydrocarbons and NO_x), aerosols, and major greenhouse gases (CO_2, CH_4, N_2O). The primary platforms are the NASA DC-8 (ceiling altitude 12 km) and P-3B (ceiling altitude 7 km) aircraft. It is expected that the INTEX-NA intensive campaigns (Years 2004 and 2006) will overlap with observations from satellites (Terra/Aura/Envisat) and other airborne platforms (Singh and Jacob, 2000; Wofsy et al., 2001). INTEX-NA will support and collaborate with these activities and benefit from the combined perspective afforded by ground based, aircraft, and satellite measurements.

However, it is being designed as a "stand alone" mission such that its successful execution is not contingent on the implementation of other programs.

North America is an industrialized region and the task of characterizing chemical inflow-outflow-transformations here is better constrained than elsewhere due to excellent meteorological coverage, relatively reliable emission inventories, and fairly detailed documentation (from both an observational and modeling perspective) of the chemistry of the continental boundary layer. INTEX-NA will focus its activities on the western Atlantic, eastern Pacific, Gulf of Mexico, and selected continental source regions. INTEX-NA is a two phase experiment with Phase A to be performed during summer when biogenic sources/sinks of NMHC and greenhouse gases, anthropogenic influence on tropospheric ozone and OH, and the climatic effect of midlatitude aerosols are all at or near their maximum (Finlayson-Pitts and Pitts, 2000). The ideal timing for Phase B is late spring when the Asian impact on North America is at its peak (Prospero and Savoie, 1989; Yienger et al., 2001). These seasons also conveniently overlap with periods when the terrestrial biosphere is a net sink (summer) and a net source (spring) of carbon (Sarmiento and Wofsy, 1999; Potter and Klooster, 1999).

A comprehensive study like INTEX-NA has not been previously performed over North America. Past observational programs over the north Atlantic (e. g. NARE, AEROCE, TARFOX) have lacked high-altitude, far-ranging aircraft platforms and often adequate chemical instrumentation for many trace species (Dickerson et al., 1995; NARE I, 1996; NARE II, 1998; Russell et al., 1999, Prados et al., 1999, Cooper et al., 2001). The SONEX DC-8 mission in Sept-Oct 1997 operated over the North Atlantic, but its primary objective (to assess the impact of aircraft NO_x emissions) kept it in the UT/LS region (SONEX I, 1999; SONEX II, 2000). No dedicated observational effort has yet been made in the region of the eastern Pacific to assess the transoceanic impact of Asian emissions on North American air quality. An aircraft campaign tentatively planned by NOAA in spring 2002 is expected to provide the first exploration of this issue. The scientific output from INTEX-NA should be directly applicable to issues involving air quality, carbon cycle, and satellite observations over North America.

II. SCIENTIFIC OBJECTIVES

The INTEX-NA aircraft mission will provide the observational database needed to constrain and evaluate model estimates of the inflow and outflow of chemicals over North America. The constituents of primary interest are ozone and its precursors (hydrocarbons and NO_x), aerosols, and major greenhouse gases (CO_2, CH_4, N_2O). 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 including satellite observations. Synthesis of the ensemble of observations from surface, airborne, and space platforms with the help of 3-D models will be used to achieve the following main INTEX-NA objectives:

(1) Quantify the export, chemical evolution, and transformations of radiatively and chemically important trace gases and aerosols from North America to the western Atlantic (Phase A)

(2) Quantify the impact of Asian pollution on the eastern Pacific as input to North America (Phase B)

(3) Elucidate mechanisms and pathways associated with the transport and transformation of these trace chemicals

(4) Utilize INTEX-NA airborne platforms to test and evaluate satellite (Aura/Terra) observations in the troposphere

(5) Contribute to carbon cycle research with a focus on providing the vertical and horizontal structure of climatically relevant trace gases and aerosols across North America

Additional important tasks include characterization of air masses entering the United States from its southern and northern boundaries, inter-comparison of observations from multiple airborne platforms, and the comparison of measured chemical fields with those predicted 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.

We plan to develop strong collaborations with other observational programs towards meeting the above objectives. Integration of the space based (Terra, Aura, Envisat) and airborne observations will be of particular interest. Additional collaborations are being developed with NACP, NOAA/UNH, and European field programs (UT/LS, WAM) which are expected to operate concurrently with INTEX-NA. INTEX-NA will greatly enhance our quantitative understanding of chemical budgets over North America in a way that improves continental source/sink estimates and their relation to global atmospheric chemistry perturbations.

III. INTEX-NA Mission Plan

The design of the INTEX-NA mission plan is guided by past experience, meteorological considerations, and results from several 3-D modeling studies to understand the continental outflow and long range transport and transformation of chemicals. In the sections below we provide brief information on the various components of INTEX-NA.

A. Meteorological setting

Typical meteorological features that represent the two phases of INTEX-NA, including flow patterns and middle and high cloudiness, are depicted in Figure 1. A typical non-El Niño year (1996) is chosen for the purpose of illustration. The cloudiness information is based on 11 year average (1983-1993) ISCCP data (http://isccp.giss.nasa.gov/isccp.html), while the flow fields are averages of 700 mb NCEP data over the months of July (Figure 1a) and April (Figure 1b), respectively. ISCCP middle clouds have tops between 680 and 440 mb, while ISCCP high clouds have tops above 440 mb. Over periods of several days substantial deviations from these mean patterns are frequently observed.

Previous aircraft campaigns and model analyses have identified several mechanisms that can transport pollutants over long distances. Deep convection, both over central and eastern North America (Thompson et al, 1994) and Asia (Kritz et al, 1990) can move surface air to the upper troposphere, where jet streams of 20-40 ms^{-1} move the pollutants across either the Atlantic from North America or the Pacific from Asia in a few days. Shallower convection excited by midlatitude frontal systems reaches midtropospheric levels where the lower portions of the jet stream have been shown to transport polluted air well into the North Atlantic (Prados, et al, 1999). The same mechanism lifts Asian pollutants out of the boundary layer into low-level westerlies, transporting them to the North American West Coast, where they can reach the surface via large-scale subsidence. Lifting on a large scale (as opposed to a convective scale) ahead of frontal systems over the North Atlantic can move pollutants from the North American boundary layer to midtropospheric levels, where jet streams transport them to Europe (the "warm conveyor belt" -- Stohl and Trickl, 1999). Finally, pollutants can be transported across the Atlantic in both directions by boundary layer flows (IGAC, 2001).

INTEX-NA Phase A and B take place in the summer and spring seasons, respectively. In summer, the circulation is dominated by the east Pacific and Bermuda subtropical high pressure systems. The north side of the Bermuda high (Figure 1a) produces a northeastward flow which is coherent enough to transport polluted air in the boundary layer to the mid-Atlantic (Parrish et al, 1998), though transport across the Atlantic to European sites is infrequent. This flow is modulated by midlatitude weather systems which produce cold fronts that sweep eastward into the Atlantic out of the northeastern and mid-Atlantic US. The synoptic scale weather systems during this season are weaker than at other seasons and stagnation episodes, coupled with summer high temperatures, can lead to severe pollution episodes over the continent. Flow on the south side of the Bermuda high can transport European pollution to North America (IGAC, 2001). It also advects warm moist air westward and northward into Mexico and the central US, leading to favorable conditions for deep convection over the North American Cordillera and the eastern US (as indicated by the high incidence of middle and high level cloudiness in Figure 1a). This convection is often diurnal in nature, though a significant portion is triggered by eastward moving weather systems from Canada. This convection feeds boundary layer air into the middle and upper tropospheric jet stream, which quickly transports air eastward across the Atlantic. During the Phase A period, convection is also strong over the Asian mainland and the South China Sea, and a similar mechanism leads to rapid high-level transport across the Pacific to North America. The Pacific high produces strong subsidence over the US West Coast, which suppresses moist convection. Outflow from California is both to the southwest in the Pacific High circulation and to the east where strong dry convection lifts pollutants into the mid-tropospheric eastward flow. In central North America, north of 40 degrees, the lower tropospheric flow is from the northwest (Fig 1a), advecting pollutants from Canadian forest fires into the east central US (Wotawa and Trainer, 2000).

The meteorological conditions for Phase B are different in several important respects. The oceanic high pressure systems are weaker and further south, the lower level eastward flows are stronger (Figure 1b), midlatitude weather systems are stronger, and convection in the North American region is, with the notable exception of the south central US, shallower. Also, after the cold winter season the overall stability of the atmosphere is lower. These meteorological differences have important consequences. First, the lower stability and stronger midlatitude weather systems limit the development of stagnation episodes over the North American continent. Second, the stronger low-level flow allows pollution to cross the Pacific in a coherent way (Staudt, et al, 2001), and turn southwestward at the North American coast. The altitude distribution of this pollution flow changes as the season progresses. During early spring the flow is well above the boundary layer because westerlies off the Asian coast do not extend to the surface. By April, however, the "river of pollution" across the Pacific from Asia extends to altitudes below 1 km. A similar pattern appears to be present in the Atlantic, with North American surface pollution episodes observed over Europe. Third, the stronger midlatitude weather systems (as indicated by the greater incidence of middle and high level cloudiness aligned with the eastward flows off the east coasts of Asia and North America (Figure 1b) lead to substantial synoptic scale lifting. This "warm conveyor belt" carries polluted air upward and northeastward from the North American boundary layer into the middle to upper tropospheric region, where it is transported rapidly eastward. Fourth, the role of convection is different than in the summer. Truly deep convection to the top of the troposphere is confined to the central US, where some of the most violent convection on earth is produced by warm moist air flowing northward from the Gulf of Mexico ahead of strong eastward moving cold fronts. The operational sites selected for the conduct of INTEX-NA (Figures 1 and 2) should make it possible to access the predominant inflow and outflow regions over North America.

B. Measurement priorities and payload

Primary airborne measurements: The DC-8 and the P-3B aircraft will include a suite of instruments to measure long-lived trace gases, photochemical oxidants, aerosols, and their precursors. The Priority measurements, reflecting the focus of the mission, for these aircraft are listed in Table 1. 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 to the GTE program, it is expected that at least one such exploratory instrument will be included in the payload. Table 1 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.

Satellite measurements: Synthesis of satellite data with aircraft observations is an important aspect of INTEX-NA. Several satellite instruments are expected to be operational during the two phases of INTEX-NA. Principal satellite instruments expected to provide information on tropospheric composition are listed in Table 2. Species for which retrieval capability has been carefully assessed include O_3, CO, H_2O, NO, NO_2, HNO_3, SO_2, HCHO, BrO, and aerosol. Additional research level products are also expected. TES, for example, has the ability to provide “special research products” which could include H_2O_2, acetone, methanol, HCN, HNO_4, SO_2, and PAN (Beer et al., 2000; EOS, 2001). Active partnership between the INTEX-NA and satellite instrument science teams will be developed.

Ozonesonde measurements: Ozonesondes have been very useful in interpreting data from aircraft campaigns (NARE, 1996). 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 2a). 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). Canadian investigators may augment these during INTEX-NA. Collaborative efforts will ensure that these and other ozonesonde data become available to INTEX-NA investigators for post mission analysis.

Carbon cycle measurements: The DC-8 and P-3 B will measure a complete suite of carbon containing species including CO_2, CO, CH_4, NMHC, and aerosol carbon (Table 1). Currently surface based measurement of CO_2 and relevant meteorological parameters are underway from three towers (≈ 20 km apart) in the vicinity of the Rhinelander, WI site. These measurements are expected to continue. Additional ground based and airborne measurements by the NACP are possible at this site but have not yet been fully finalized (Wofsy et al., 2001). Retrieval of CO_2 column densities from space based instruments (e. g. SCIAMACHY) is also possible. We note here that the measurement of a large suite of organic and inorganic tracers by INTEX-NA greatly aids the interpretation of all carbon cycle observations. In short, INTEX-NA will make critical carbon cycle measurements on a "stand alone" basis and greatly add to and complement other concurrent efforts.

C. Model simulations

INTEX-NA observations both rely on and help in the further development of photochemical theory and models. Interpretation of the combined aircraft, satellite, and ground-based data in terms of continental inflow/outflow fluxes and related chemical evolution will require 3-D chemical models driven by realistic meteorological fields and including detailed representations of emission inventories, tropospheric chemistry, and aerosol processes. Simulations using these models will be used: (1) pre-mission to refine the selection of operational sites and flight plans, (2) during the mission to guide day-do-day flight planning using model forecasts, thus designing the flights to optimally test the models, and (3) post-mission to evaluate emission inventories and interpret the observations quantitatively in terms of export fluxes. Co-variances between species in the continental outflow as measured by INTEX-NA will be of particular value for testing the models and for improving our quantitative knowledge on export fluxes. It is also anticipated that point modeling will be a key tool in the analysis of data collected during INTEX especially for testing photochemical theories.

D. Deployment and flight plans

The primary airborne platforms for this mission are the NASA DC-8 and the P3-B aircraft. The DC-8 will sample through the depth of the troposphere up to 12 km altitude.

The DC-8 is based at the Dryden Flight Research Center in southern California. All instrument integration and testing for the DC-8 will take place there. Similarly P3-B instrument integration and test flights will take place from the Wallops Flight Facility. Figure 2 gives nominal flight tracks for Phase A and B for the DC-8 and the P-3B. The two aircraft will be coordinated to achieve maximum synergy between surface and free tropospheric outflow features. The DC-8 is the platform of choice for the task of large-scale chemical characterization of inflow, outflow, and transcontinental gradients. The P3-B is best suited for lower tropospheric and boundary layer studies including processes of exchange with the free troposphere.

Table 3 provides a summary of the nominal flight plans, flight hour allocations, and achievable objectives. The Bangor, New Orleans, and Rhinelander sites are particularly suited to study North American outflow, inflow from the southern boundary (Gulf of Mexico/Mexico), and characterization of continental gradients, respectively. Both recently polluted and highly processed air masses will be sampled from these sites. Similarly the Seattle and Dryden locations provide excellent opportunities for inflow characterization. All of the selected deployment sites can support large missions and are suitable for INTEX-NA objectives. Alternate bases of operation are also available to accommodate unexpected conditions.

Final flight planning will be done in the field with the benefit of satellite imagery and forecasted weather conditions in a manner similar to previous GTE missions (especially PEM and TRACE). It is anticipated that 3-D model simulations will be performed in the field based on forecasted weather conditions. These simulations will predict chemical and aerosol fields and will guide flight planning efforts. Remote sensing measurements (e. g. O_3, aerosol) on board the airplane 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. Our previous experience (SONEX) has shown that this can be accomplished with careful and early planning. Here we briefly discuss the three main mission foci relevant to INTEX-NA objectives.

<u>Inflow-outflow, transcontinental characterization, and photochemistry missions:</u> The main objective of these missions will be to characterize (1) inflow to North America from the Pacific (2) inflow to the continental U. S. from the northern boundary (Canada), (3) inflow to the continental U. S. from the southern boundary (Gulf of Mexico/Mexico), (4) North American outflow to the Atlantic and (5) chemical composition and gradient characterization across North America. Many of the photochemistry and intercomparison goals will be part of these missions. The primary operational sites (Figure 2) have been selected to conveniently address these objectives. These objectives will require targeted observations under a variety of meteorological conditions that are critical to the transport of pollution in the troposphere. Transport events involving deep and low level convection, frontal lifting, outflow behind fronts, and subsiding air masses are potential targets.

The DC-8 and P3-B platforms will be used in coordination as well as independently. GTE has considerable experience, most recently from TRACE-P, for the deployment of these two aircraft to address INTEX-NA type objectives. The two aircraft could be used to sample different outflow regions on any particular day. Detailed flight planning will be done after the selection of the science team and during the conduct of the mission.

Satellite observations: Synthesis of satellite and airborne observations is an integral part of INTEX-NA. INTEX-NA has two inter-linked goals in this area: (1) utilize available satellite data to enhance the spatial and temporal coverage of airborne observations, and (2) collect a body of reliable data in the troposphere that will permit test and evaluation of selected space borne instruments (e. g. MOPITT, TES and SCIAMACHY). The first goal is not limited to any specific instrument or satellite but depends on the acquisition of all available data. The second goal is more restrictive and some level of prioritization is necessary. Our primary focus during both Phases A and B will be the Aura satellite and within it the TES instrument which is expected to make an array of chemical measurements (Table 2) in the troposphere (Beer et al., 2001). We recognize that there may be delays in the launch of new satellites. However, because INTEX-NA is to be conducted in both 2004 (Phase A) and 2006 (Phase B), the chances of successful concurrent operation are greatly enhanced. The nominal life span of Terra (5 years) should keep it operational through Phase A. Should it turn out to be more desirable, depending on future developments, Phase B could also be performed in 2005.

INTEX-NA will provide tropospheric composition data (in-situ and remote) over a wide range of conditions for evaluating the performance of some of the key space-borne instruments. During several targeted opportunities (6 to 8) we will under-fly the satellite along its orbit in the upper troposphere and/or provide a concurrent detailed vertical profile of chemicals through the accessible troposphere using the DC-8. All such measurements will be performed within ±30 minutes of the satellite overpass. Additional data will be collected to assess the variability in air mass composition over short time periods (hours). Since cloud free conditions are highly desired, these missions will be planned based on the latest satellite cloud imagery and meteorological forecasts. Coordination with Air Traffic Control (ATC) over various regions of North America will be critical to accomplish this objective. It is recognized that extensive independent efforts are underway to develop strategies for Aura instrument validation in the stratosphere and the troposphere (EOS, 2001). INTEX-NA is designed to complement these activities. Close interaction between the INTEX-NA and Aura science teams will be developed.

Carbon Cycle Studies: INTEX-NA will contribute to carbon cycle research independently and in collaboration with NACP. INTEX-NA will make highly precise in-situ measurements of carbon species (CO_2, CO, CH_4, NMHC, and Aerosol C) that are key components of the carbon cycle. Much of the carbon cycle research effort to date has been performed within forested ecosystems. One of the critical needs of carbon cycle research has been to obtain vertical concentration profiles of key species throughout the troposphere in continental source/sink regions (Sarmiento and Wofsy, 1999). INTEX-NA is ideally suited to perform this role. Coastal and continental operational sites will allow the development of a curtain profile of greenhouse gases and other pollutants across North America. Such measurements will help to develop quantitative chemical budgets on continental scales and provide answers to key questions pertaining to land sinks over North America. The seasons chosen for INTEX-NA are particularly suited for carbon cycle studies as they overlap with periods when the terrestrial biosphere is both a net sink (summer) and a net source (spring) of CO_2. The Rhinelander, WI site was selected in part because of the ongoing CO_2 measurements from three towers near this site. It is anticipated that airborne flux measurements will be a key component of NACP efforts requiring further coordination with the P3-B.

E. Collaborations and links

We expect significant inter-agency and international collaborations in support of INTEX-NA. Several satellites with instruments that will make chemical measurements in the troposphere are planned to be launched by U. S. (Aura/TES) and Europe (Envisat/SCIAMACHY). Additional airborne platforms are expected to be deployed by NOAA (F. Fehsenfeld-private communication, 2001) and by NACP. European programs such as EXPORT-E2, UT/LS, and the WAM (West African Monsoon) experiment have significant tropospheric chemistry components and are keen to collaborate with INTEX-NA. The acquisition of a new high altitude (to 10 km) capable aircraft (BAe-146) by European scientists will make this collaboration extremely fruitful. US EPA and Canadian scientists are contemplating major modeling/experimental efforts to investigate outflow of pollutants from North America. Air Resources Board of California has plans for a field study over California with boundaries that extend over the eastern Pacific. It is possible that Asian partners will organize field experiments in the western Pacific as well. The Global Modeling Initiative (GMI) is a clear beneficiary of these observations and a partner in this effort. Many of these efforts are in their developmental stages and will be finalized during the next year or two in coordination with INTEX-NA. A global protocol involving data sharing and cooperation will be developed to encourage free flow of information among all parties involved. To ensure a greater possibility of cooperation, key representatives from potential partner activities are members of the INTEX-NA steering committee.

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APPENDIX 1: Acronyms relevant to this document

AEROCE: Atmospheric/Ocean Chemistry Experiment
ATC: Air Traffic Control
EXPORT: European Export of Precursors and Ozone by Long-Range Transport
GOME: Global Ozone Monitoring Experiment
GTE: Global Tropospheric Experiment
GMI: Global Modeling Initiative
HIRDLS: High Resolution Dynamic Limb Sounder
IGAC: International Global Atmospheric Chemistry
INTEX-NA: Intercontinental Chemical Transport Experiment-North America
ISCCP: International Satellite Cloud Climatology Project
ITCT: Intercontinental Transport and Chemical Transformation
MIPAS: Michelson Interferometer for Passive Atmospheric Sounding
MOPITT: Measurement of Pollution in the Troposphere
MODIS: Moderate Resolution Imaging Spectroradiometer
NACP: North American Carbon Program
NARE: North American Regional Experiment
NCEP: National Center for Environmental Prediction
NMHC: Nonmethane Hydrocarbons
NOAA: National Oceanic and Atmospheric Administration
OMI: Ozone Monitoring Instrument
PEM: Pacific Exploratory Mission
SAGE: Stratospheric Aerosol and Gas Experiment
SCIAMACHY: Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
SONEX: SASS Ozone and NO_X Experiment
TARFOX: Tropospheric Radiative Forcing Observation Experiment
TES: Tropospheric Emission Spectrometer
TOMS: Total Ozone Mapping Spectrometer
TRACE: Transport and Chemistry Experiment
UNH: University of New Hampshire
UT/LS: Upper Troposphere/Lower Stratosphere
WAM: West African Monsoon

Table 1: 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
NO	1	1	5 ppt	5 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	1	1	10 ppb	5 s
N_2O	2	2	1 ppb	10 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
Bulk aerosol composition (organic & inorganic)	2	2	20 ppt	10 min
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
OCS	4	4	5 ppt	5 min
Single particle composition	4	4	D>50 nm	1 s
Radionuclide (^{22}Rn, ^{7}Be, ^{210}Pb)	4	4	0.05-1 Bq/SCM	10 min
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
j-uv (spectral radiometers)	2	2	10^{-5}/s	10 s
H_2O (nadir/zenith)	3	4	20 ppm	Z<500 m
Extinction/scattering	3	3	--	1 s

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.

Table 2. Major space-based tropospheric chemistry trace gas and aerosol measurements

Sensors	TOMS/ TRIANA*	GOME	MOPITT	MODIS	SCIAMACHY	MIPAS	TES#	HRDLS	OMI*	MLS	SAGE III
year	1979-	1995	1999	1999	2002	2002	2003	2003	2003	2003	2004
O_3	column	column			column+, Δz= 3-4km limb	z>5 km limb	Δz= 2/4 km limb/nadir	Δz= 1 km (UT)	column	UT	Δz= 1km (UT)
H_2O	column			column	column+, Δz= 3-4km limb	z>5 km limb	Δz= 2/4 km limb/nadir	Δz= 1 km (UT)	column	UT	Δz= 1km (UT)
CO			3-4 levels		column+, Δz= 3-4km limb	z>5 km limb	Δz= 2/4 km limb/nadir			UT	
NO							tropical UT; Δz= 2 km				
NO_2		column			column+, Δz= 3-4km limb				column		
HNO_3						UT	UT; Δz= 2 km	Δz= 1 km (UT)			
CH_4			column		column+, Δz= 3-4km limb		column				
CH_2O		column			column+ Δz= 3-4km limb				column		
SO_2		column			column		column		column		
BrO		column			column+, Δz= 3-4km limb						
Aerosol	column			column	Column/profiles				column		Δz= 1km (UT)

*TOMS has been in operation since 1979. Last launch was in 1996 and data continue to be collected at this time. TRIANA and OMI will take over TOMS functions in year 2003. Much information on the Aura instruments (TES, HRDLS. OMI and MLS) is available from http://eos-chem.gsfc.nasa.gov/.

#A number of "special research products" such as acetone, methanol, H_2O_2, HCN, NH_3, HNO_4, SO_2, and PAN are possible.

UT= upper troposphere

Table 3: Operational sites, flight hour allocation, and main objectives

INTEX-NA	**DC-8 Flights**				**P3-B Flights**			
	Type*	No.	Hours	Objectives#	Type	No.	Hours	Objectives#
Phase A	Test flights-DR	3	13	7	Test flight-WL	3	13	7
	Missions- DR	3	27	4,6,8,9	Transit to RL	1	8	8
	Transit to RL	1	9	8	Missions- RL	5	40	2,3,5,8,9
	Missions- RL	3	27	2,3,5,6,8,9	Transit to BG	1	8	8
	Transit to BG	1	9	8	Missions- BG	5	40	1,9
	Missions- BG	5	45	1,6,9	Transit to NO	1	8	8
	Transit to NO	1	9	8	Missions- NO	5	40	3,8,9
	Missions- NO	3	27	3,6,8,9	Transit to WL	1	8	8
	Transit to DR	1	9	8				
	Total	**21**	**175**		**Total**	**22**	**165**	
Phase B	Test flights- DR	3	13	7	Test flight- WL	3	13	7
	Missions- DR	3	27	1,6,9	Missions- WL	2	16	1,9
	Transit to ST	1	9	8	Transit to RL	1	8	8
	Missions- ST	5	45	1,6,9	Transit to ST	1	8	8
	Transit to RL	1	9	8	Missions- ST	5	40	3,9
	Missions- RL	3	27	2,3,5,6,9	Transit to RL	1	8	8
	Transit to BG	1	9	8	Missions- RL	5	40	2,3,5,8,9
	Missions- BG	3	27	1,6,9	Transit to BG	1	8	8
	Transit to DR	1	9	8	Missions- BG	3	24	1,9
					Transit to WL	1	8	8
	Totals	**21**	**175**		**Total**	**23**	**173**	

*DR-Dryden Flight Research Center, CA; RL-Rhinelander,WI; BG-Bangor, ME; NO-New Orleans, LA; ST-Seattle, WA; WL-Wallops Flight Facility, VA.

#1-North American out flow to the Atlantic, 2-Inflow from the northern boundary (Canada), 3-Inflow from the south (Gulf of Mexico/Mexico), 4-Inflow to North America from the Pacific, 5-BL/FT exchange studies, 6-Satellite under-flights, 7-Test flights, 8-Chemical composition and gradient characterization, 9-Photochemistry/intercomparison objectives.

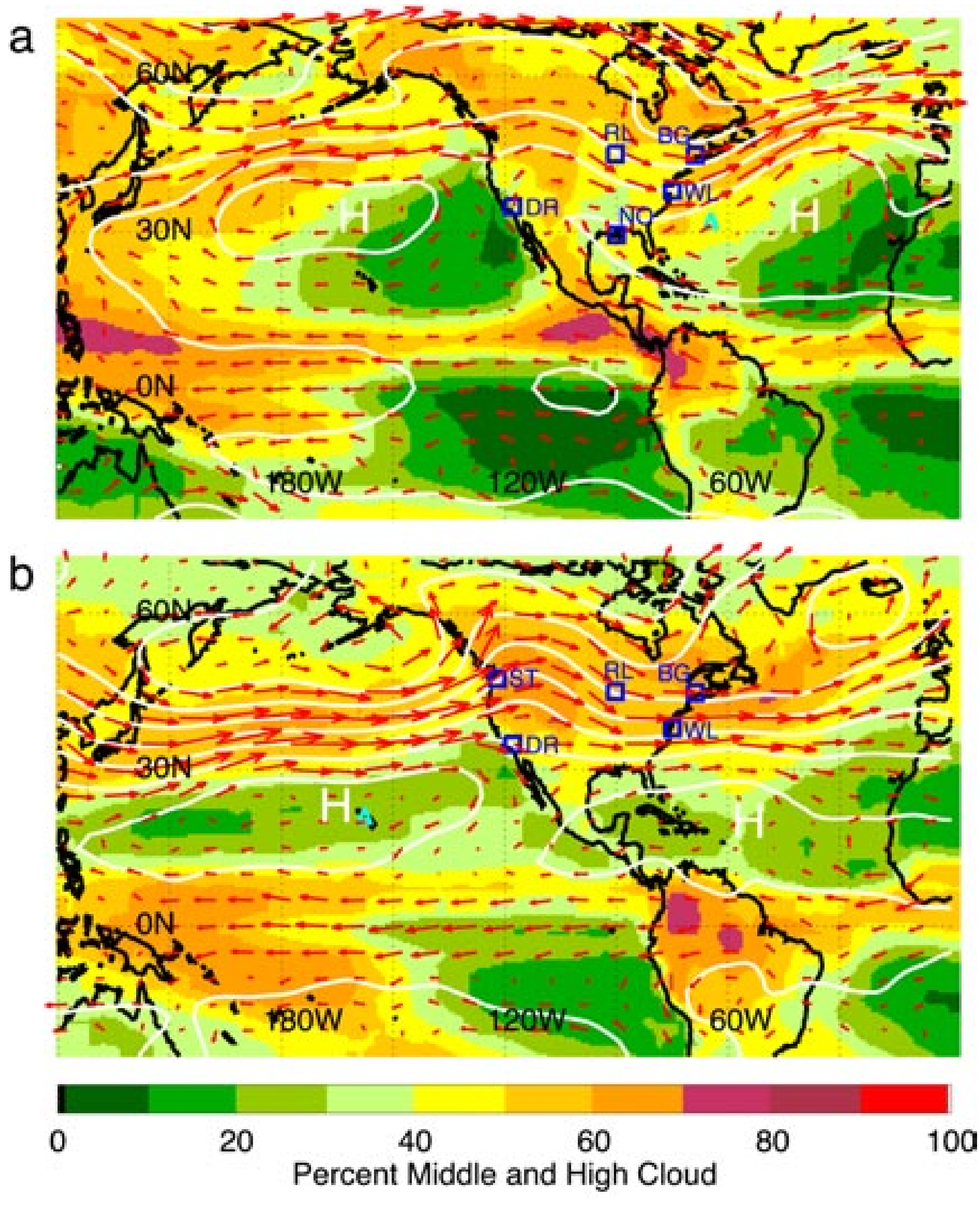

Figure 1: (a) Typical meteorological features at 700 mb during July in the eastern Pacific and western Atlantic (Phase A). Plotted are average 700mb geopotential heights (50 meter contours in white), the flow patterns (red arrows), and 11 year ISCCP middle and high cloud amounts (colors) for July 1996. The sites of intensive operations are indicated in blue. (b) As in (a) except for April (Phase B).

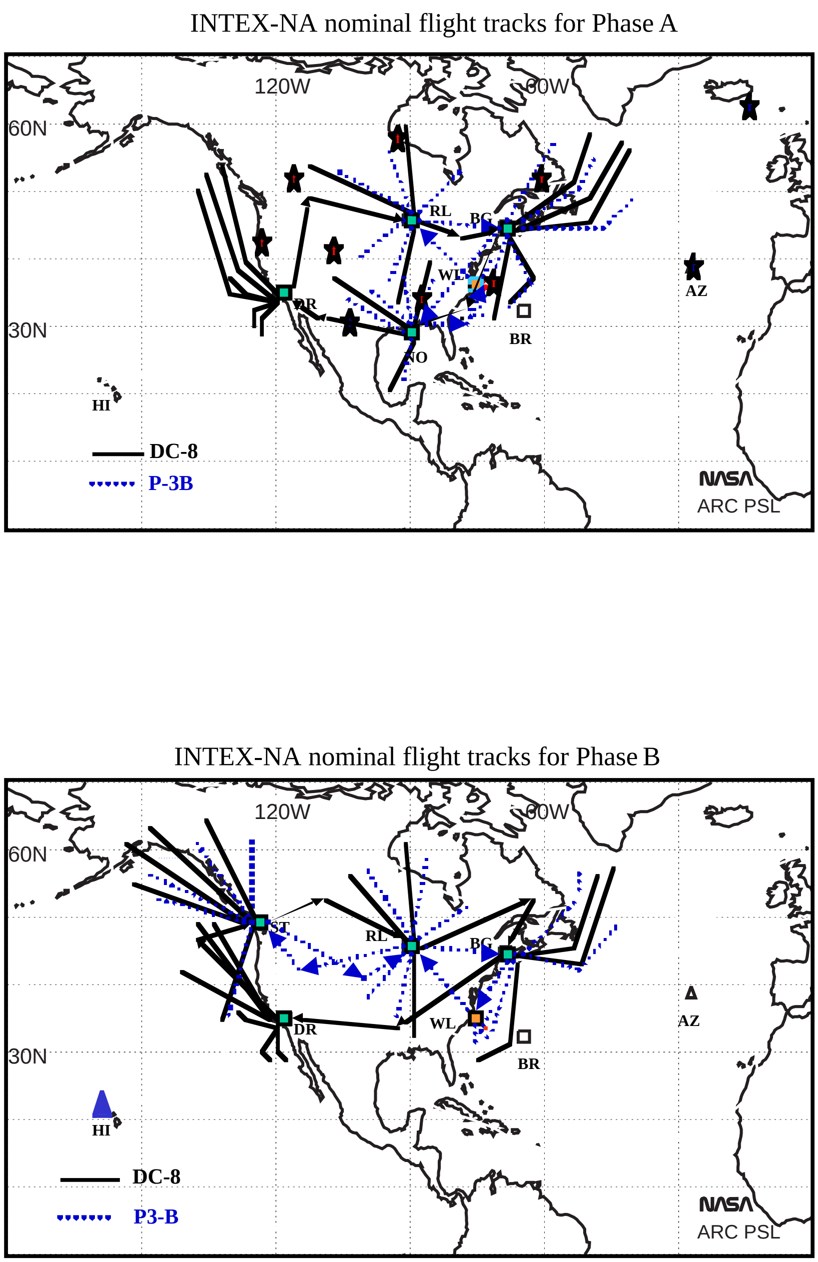

Figure 2: Nominal INTEX-NA flight tracks. DC-8 tracks are shown in solid black lines while P3-B tracks are in dashed blue lines. Red stars in the top panel show existing ozonesonde stations. Blue stars indicate possible augmentations. Amber filled color implies nominal operation for test flights.