The Intercontinental Chemical Transport Experiment – Phase B (INTEX-B): An update

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ABSTRACT

INTEX-NA* (http://cloud1.arc.nasa.gov) is a two phase experiment that aims to understand the transport and transformation of gases and aerosols on transcontinental/intercontinental scales and assess their impact on air quality and climate. The primary constituents of interest are ozone and precursors, aerosols and precursors, and the long-lived greenhouse gases. The first phase (INTEX-A) was completed in the summer of 2004 and the second phase (INTEX-B) is to be performed in the spring of 2006. This document is intended to provide an update on the goals of INTEX-B and define its implementation strategy. The scientific goals envisioned here are based on the joint implementation of INTEX-B, MIRAGE-Mex (http://mirage-mex.acd.ucar.edu/index.html) and DLR/IMPACT studies and their coordination with satellite observations. In collaboration with these partners, the main goals of INTEX-B are to:

- Quantify the transpacific transport and evolution of Asian pollution to North America and assess its implications for regional air quality and climate;
- Quantify the outflow and evolution of gases and aerosols from the Mexico City Megaplex;
- Investigate the transport of Asian and North America pollution to the eastern Atlantic and assess its implications for European air quality;
- Validate and refine satellite observations of tropospheric composition;
- Map emissions of trace gases and aerosols and relate atmospheric composition to sources and sinks

The INTEX-B field study is to be performed during an approximate 8-week period from March 1 to April 30, 2006. The first part of the study (INTEX-B/Part I) will be performed during March 1-31 and will focus on Mexico City pollution outflow while the second part (INTEX-B/Part II) will be performed during April 1-30 and will focus on Asian pollution inflow. Several national and international partners are expected to join with INTEX-B and its scope is likely to expand in the coming months. At the moment, the principle INTEX-B partners are the NSF led MIRAGE-MEX and the German/DLR led IMPACT. Both high flying (e. g. the NASA DC-8 and DLR Falcon-20) and low flying (e. g. NSF/NCAR C-130) airborne platforms are expected to be available for INTEX-B. These airborne platforms, with possible augmentations by others, will be equipped to perform a comprehensive suite of gas, aerosol and radiation measurements.

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* See Appendix for explanation of Acronyms

This study is planned assuming that approximately 180 flight hours will be available for each of the major airborne platforms such as the NASA DC-8 and the NSF/NCAR C-130. Principal operational sites and dates for the spring 2006 activity are tentatively selected to be:

- NASA DC-8 (Houston, TX/March 1-31; Hilo, Hi/April 1-12; Anchorage, AK/April 13-30)
- NSF/NCAR C-130 (Tampico, MX/March 1-31; Seattle, WA/April 1-30)
- DLR Falcon-20 (Oberpfaffenhofen, Germany/April 1-30)

To expand the temporal and spatial scale of airborne measurements, INTEX-B will closely coordinate its activities with satellites platforms especially Aura, Aqua, Terra, and Envisat. A majority of the “standard” and “research” products to be retrieved from satellite observations will be measured during INTEX-B. Validation of satellite observations of tropospheric composition will receive high priority. Central to achieving INTEX-B objectives is the ability to relate space-based observations with those from airborne and surface platforms. The overall experiment will be supported by forecasts from meteorological and chemical models, satellite observations, surface networks, and enhanced O3-sonde releases.

In addition to understanding the life-cycle of pollutants downwind of large sources regions, INTEX-B will allow us to test and improve the present capability of chemical transport models and help to advance their integration with space-based, airborne, and surface-based observing systems. Joining resources, the spring 2006 field experiments will greatly add to our ability to quantify pollution transport and its evolution from local to intercontinental scales. Participation by researchers from academia, government labs, and other research institutions is essential for the success of this campaign.

I. BACKGROUND

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? As has been stated in the original INTEX-NA white paper (Singh et al., 2002; http://cloud1.arc.nasa.gov), a key requirement in addressing this vision 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 of human influence on climate and air quality

The export of air pollutants from urban to regional and global environments is a major concern because of wide-ranging consequences for human health and ecosystems, visibility degradation, weather modification, changes in radiative forcing, and tropospheric oxidation (self-cleaning) capacity. The complexities involved in quantifying the role of long-range pollution transport on environmental degradation have led to the launching of an international research initiative (IGAC-ITCT; http://www.igac.noaa.gov/ITCT.php). INTEX-NA is a NASA led integrated field experiment within the IGAC-ITCT initiative with the goal of understanding the transport and transformation of gases and aerosols on transcontinental/intercontinental scales and assessing their impact on air quality and climate. Its first phase (INTEX-A) was completed in the summer of 2004 and its second phase (INTEX-B) is to be performed in the early spring of 2006. Although the main features of INTEX-B were discussed in the original INTEX-NA white paper, much has transpired during the last three years to make an update necessary. In this document, we focus on those aspects that are most relevant to the conduct of the upcoming INTEX-B field mission.

II. INTRODUCTION AND OVERVIEW

In recent decades a mounting body of atmospheric data have shown that gas and aerosol pollutants are routinely transported on intercontinental scales and can influence air quality and regional climate in downwind regions (Holloway et al., 2003; Stohl, 2004; JGR-Atmospheres 2004a,b). Multiple studies have documented the transport of Asian pollution to North America (Jaffe et al., 1999; Jacob et al., 1999; VanCuren, 2003) and Europe (Lelieveld et al., 2002). 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 highly episodic but most frequent and rapid in spring, when frontal activity is maximum and the atmospheric circulation is strong (Yienger et al., 2000). There is however, evidence to suggest that Asian influences are not limited to the spring period and are present throughout the year (VanCuren et al., 2004; INTEX-A unpublished data). Dramatic evidence for transpacific transport of Asian air to North America is offered by Asian dust plumes, which have been tracked by satellites across the ocean and found to cause large-scale exceedances of air quality standards at sites in the western United States (Husar et al., 2001). Asian pollution plumes have also been observed from aircraft and at ground sites along the west coast. Figure 1 shows a schematic of Asian air transport for the month of April along with 7-day climatological trajectories derived from a 15-year (1979-1993) global data set prepared by Eckhardt et al. (2004). Approximately 10% of all Asian trajectories crossed 140W longitude within 7 days enroute to North America.

An example of an Asian pollution outflow event is shown in Figure 2. A major Asian outflow pollution event occurred in February 2001 and was monitored by the MOPITT satellite, which measures total CO column abundance, and by the NASA DC-8, which was on its transit through Hawaii at the beginning of the TRACE-P mission (Heald et al., 2003). The plume (dark gray) is over Japan on 23 February and splits around a blocking high pressure region east of Hawaii. The northern branch was detected by the DC-8 between Hawaii and California at 6-8 km; the southern branch was detected southwest of Hawaii at 4-5 km the next day. Aircraft observations show quite different chemical evolution in the two plumes, with PAN dissociation in the southern plume resulting in O_3 production.

Both observational data and modeling studies have shown that the composition of the inflow to NA and Europe may have changed due to intercontinental pollution influences (Jaffe et al., 2003; Parrish et al., 2004; Simmonds et al., 2004). It has been suggested that surface O_3 levels entering the US and Europe may have increased by as much as 0.5 ppb/year (Figure 3) over the last two decades. 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. 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.

A second phenomenon that is receiving much attention in recent years is the impact of pollution from megacities (>10 million population) (http://mirage-mex.acd.ucar.edu/; http://www.igac.noaa.gov/MEGACITY.php). With a current population of ca. 18 million, Mexico City is one of the world's most populous tropical cities with unique emission characteristics (Molina and Molina, 2002). Three-day forward trajectories released from Mexico City for the month of March are shown in Figure 4. Some 30-50% of these trajectories reach the continental U. S. within 3-5 days. MIRAGE-Mex is an experiment designed to address major uncertainties in the transport, physical and chemical transformations, and evolving radiative properties of gases and aerosols. The focus will be on understanding the life-cycle of these pollutants, from emission to ultimate removal from the atmosphere, and especially the "middle-age" transition from urban to regional and global scales.

INTEX-B and MIRAGE-mex are planning to join forces to investigate both the "inflow of pollution to NA from Asia" as well as the outflow and evolution of pollution from "Mexico City". The long range and high altitude capability of the DC-8 and the superior low altitude capability of the C-130 greatly add to the overall experiment. Combining MIRAGE-Mex and INTEX-B enables the examination of long-range pollution from both the south/southwest and the northwest in a single study. The many advantages of this collaboration have been discussed in detail by Brune et al. (2004).

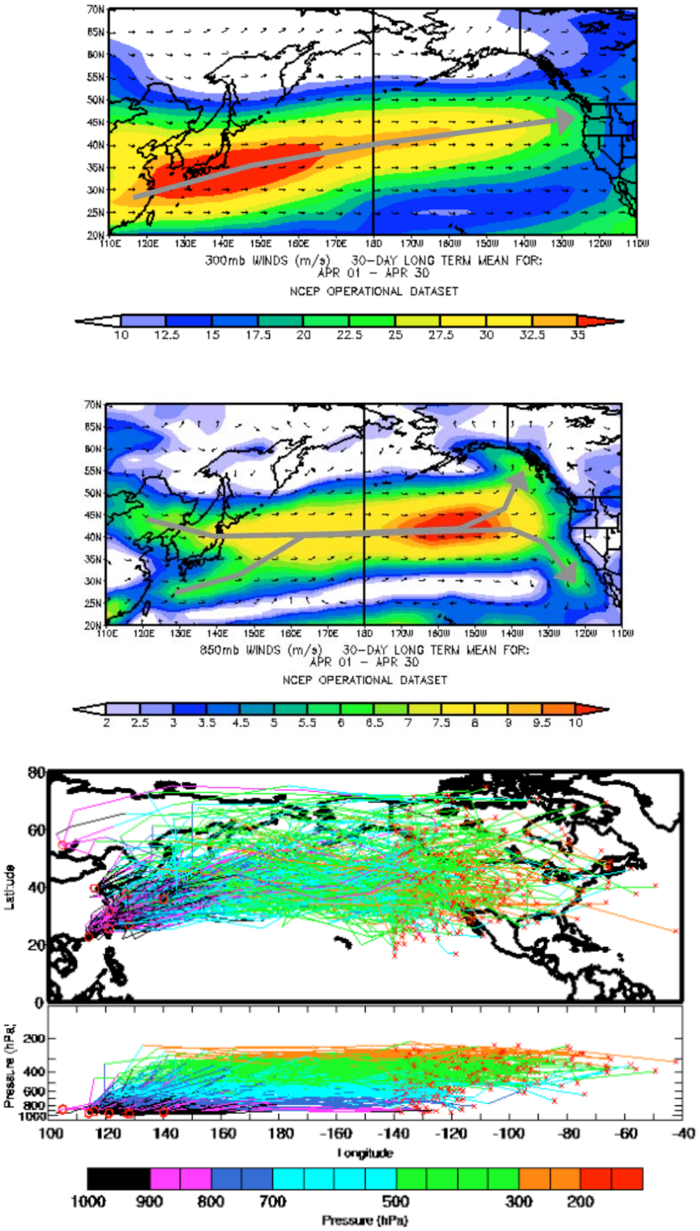
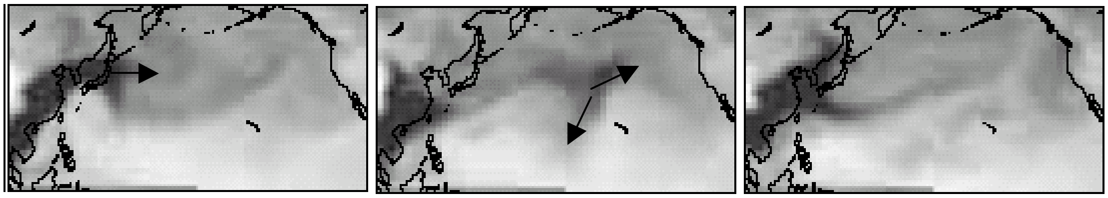


Figure 1: 300 mb winds (top), 850 mb winds (middle) and 7-day forward Asian trajectories (bottom) for the month of April. Trajectories (one per day) were released from 500 meters AGL from Irkutsk, Hong Kong, Shanghai, Taipei, Seoul, Beijing, Okinawa, Tokyo (red circles). Alternate day trajectories that were east of 140W in 7 days (approx. 10%) are shown. The trajectories are from a global 15-year data set prepared by Eckhardt et al. (2004)



23 February 2001 25 February 2001 27 February 2001

Figure 2. Model simulation of an Asian pollution plume (indicated by CO column abundance and consistent with MOPITT satellite CO column measurements) crossing the Pacific during the TRACE-P study in February 2001.

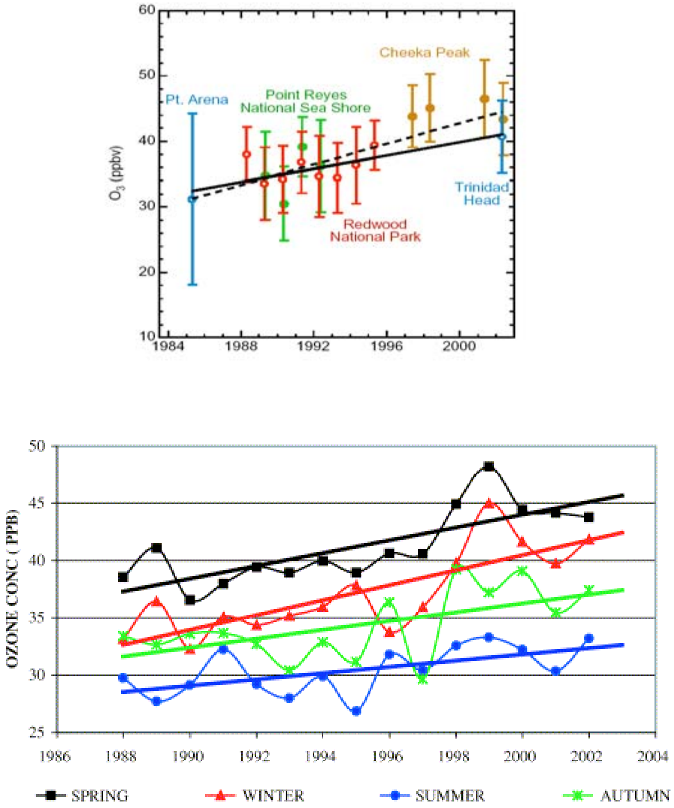


Fig. 3. Surface ozone trends in air flowing into the United States and Europe. Top Panel (Jaffe et al., 2003): Spring time ozone mixing ratios from selected sites on the west coast of united states show a mean trend of 0.5 ± 0.4 ppb/yr. Bottom Panel (Simmonds et al., 2004): Mace Head O_3 baseline monthly means from 1988-2003. Mean annual trend is 0.5 ± 0.2 ppb/yr with largest trend in winter (0.6 ± 0.3 ppb/yr) and smallest in summer (0.4 ± 0.3 ppb/yr).

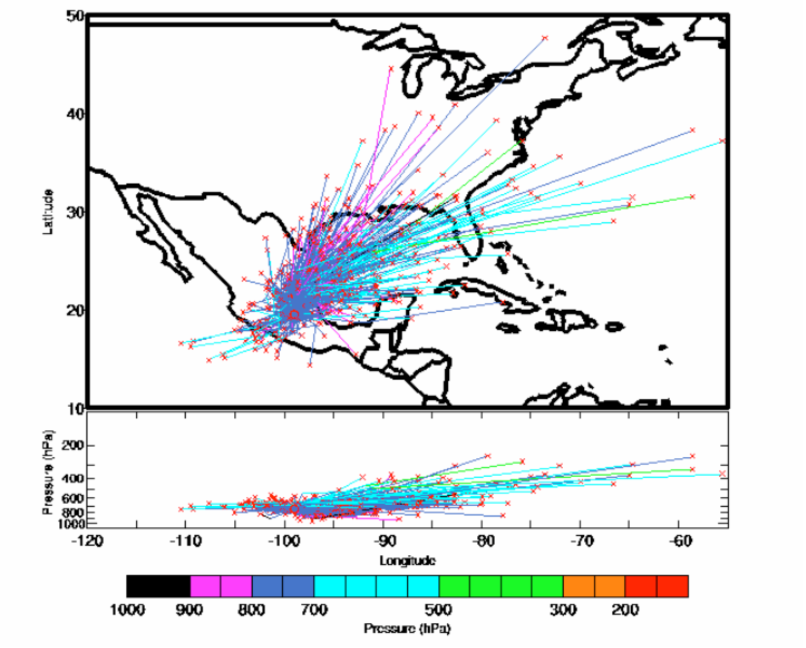


Figure 4: Three day forward trajectories from Mexico City for the month of March. Approximately 30% of these are over the United States in 3 days. The trajectories are from a global 15-year data set prepared by Eckhardt et al. (2004).

The scale of the intercontinental transport problem is extremely large and until recently the means to investigate this problem were inadequate. A major new advance has been the launch of new satellite instruments that have the capability to map pollution in the troposphere on regional to global scales (Borrell et al., 2004; Schoeberl, et al., 2004). Table 1 provides a partial list of key chemical and physical properties of interest to INTEX-B that can be measured by satellite instruments in the troposphere. Some of these instruments (e. g. TES, MIPAS) have great potential to also measure a large number of organic chemicals as research products (Beer et al. 2001, Allen et al., 2004). During INTEX-A a large number of satellite under-flights were performed to test and validate the accuracy of satellite observations from MOPITT, MISR, AIRS, and SCIAMACHY (Figure 5). These validation flights were specifically targeted in space and time to provide a large body of coincident data on gases and aerosols to both test and further refine satellite derived products of tropospheric composition. INTEX-B will perform the dual role of validating satellite observations in the troposphere as well as integrating them with in-situ observations to address stated scientific goals.

Table 1: Satellite observations of key tropospheric constituents relevant to INTEX-B

Satellite Platform*	**Instruments**	**Some key data products**	**Vertical resolution**
Aura: http://eos-aura.gsfc.nasa.gov/	TES OMI MLS	CO, CH_4, O_3, HNO_3, NO_2 O_3, NO_2, SO_2, HCHO H_2O, HCN	Trop column/4 km Trop column UT/LS
Aqua: http://eos-pm.gsfc.nasa. gov/	MODIS AIRS	Aeorosol optical depth CO	Trop column Trop column/4 km
Terra http://eos-am.gsfc.nasa.gov/	MOPITT MISR MODIS	CO Aeorosol optical depth Aeorosol optical depth	Trop column/4 km Trop column Trop column
Envisat: http://envisat.esa.int/	SCIAMACHY MIPAS	O_3, NO_2, CH_2O Trace organics	Trop column UT/LS
Calipso: http://www-calipso.larc.nasa.gov/	CALIOP	Aeorosol distribution	High resolution

*Individual web sites provides detailed measurement capabilities of these instruments

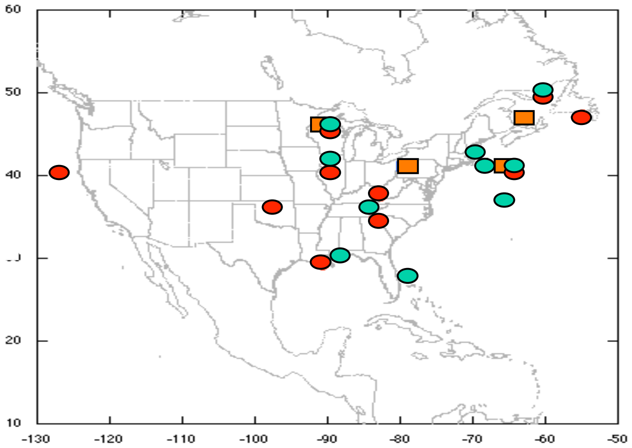


Figure 5: DC-8 satellite under-flights during INTEX-A. Aqua - Red circles; Terra - green circles; Envisat – amber squares. Typically these involved DC-8 spirals from 11 km to surface within ±30 minutes of satellite overpass and within the swaths of AIRS (Aqua), MOPITT and MISR (Terra), and SCIAMACHY- Nadir mode (Envisat) instruments.

III. SCIENTIFIC OBJECTIVES

INTEX-B is an intensive observational mission involving multiple partners with overlapping scientific objectives. The achievement of its objectives requires an integrated observational strategy and a hierarchy of global/regional models. Joining resources and capabilities with the MIRAGE-mex, DLR/IMPACT, and satellite partners, the following goals are envisioned:

(1) Characterize and quantify the transpacific transport and evolution of Asian pollution (gases and aerosols) to North America and assess its implications for regional air quality and climate;

(2) Characterize and quantify the outflow and evolution of gases and aerosols from the Mexico City Megaplex;

(3) Investigate the transport of Asian and North America pollution to the eastern Atlantic and assess its implications for European air quality;

(4) Validate and refine satellite observations of tropospheric composition;

(5) Map emissions of trace gases and aerosols and relate atmospheric composition to sources and sinks

A critical task towards the achievement of INTEX-B objectives will be inter-comparison of observations among multiple airborne and satellite 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 and southern boundaries; and the comparison of measured chemical fields with those forecasted by regional/global models. Central to achieving INTEX-B objectives will be the ability to relate space-based observations with those from airborne and surface platforms. Theories of photochemical ozone and aerosol production and loss in background and polluted air masses will be tested and the role of aerosols in radiative forcing and heterogeneous chemistry investigated. The focus will be on understanding the life-cycle of pollutants several days downwind of the source regions. Secondary goals will be to:

- Test the ability of models, both forecast and analysis, to capture the timing, morphology, and altitude of pollution plumes;
- Test the expected chemical evolution of gases and aerosols as the pollution plumes are transported
- Examine characteristics of the pollution that can affect its direct and indirect effects on climate;
- Advance the development of the integration between chemical transport models and the observing system, which includes satellites, ground-based networks, and intensive field campaigns.

IV. INTEX-B Mission Plan

INTEX-B will use the NASA DC-8 as its primary platform (ceiling 12 km, endurance 10 hours, nominal speed 400 kts). Complementing this will be the NSF/NCAR C-130 (ceiling 7 km, endurance 8 hours, nominal speed 300 kts) and the DLR Falcon-20 (ceiling 14 km, endurance 5 hours, nominal speed 400 kts). 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 most recently INTEX-A. Mission design and day-to-day flight operations will be guided by forecasts from a hierarchy of global and mesoscale models. 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. 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.

A. Measurement priorities and payload

The DC-8, C-130, and Falcon-20, possibly augmented by other more specialized aircraft, will be equipped with a comprehensive suite of in-situ and remote sensing instrumentation to provide chemical, physical, and optical measurements. 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. 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. 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. (It is recognized that instrumentation for all the measurements in Table 2 may not fit on the DC-8, and that in fact it may be more scientifically productive to have some of the measurements made from another, more specialized, aircraft. For example, in INTEX-A, measurements of aerosol optical depth spectra and solar radiative flux spectra from the J31 determined aerosol radiative effects, validated satellites, and provided remote and in situ measurements of water vapor.)

The C-130 payload has been described in the MIRAGE-Mex white paper (Madronich et al., 2004) and is very similar to that of the DC-8 described in Table 2. The Falcon-20 is a smaller aircraft that will be equipped to measure important trace gases (NO, HNO_3, NO_y, O_3, RO_2, CO, CO_2, CH_4, SO_2, H_2SO_4) and aerosols (size distribution, volatility and bulk composition) (Schlager et al., 2005). A nation-wide network of four stations that launch weekly ozone sondes 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-B intensive the frequency of releases at these stations will be augmented (3/week). It is recommended that ozonesonde releases also occur from a southern Texas site for the month of March.

Table 2: INTEX-NA payload and nominal measurement requirements for DC-8 and other more specialized aircraft

Species/parameters	Priority DC-8*	Detection limit	Nominal Resolution$^{\#}$
In-situ measurements			
O_3	1	3 ppb	1 s
H_2O	1	10 ppm (±10%)	5 s
CO_2	2	0.5 ppm	5 s
CO	2	3 ppb	5 s
CH_4	2	10 ppb	5 s
NO	2	5 ppt	5 s
NO_2	2	10 ppt	1 min
HNO_3	2	30 ppt	2 min
PAN/PPN	2	5 ppt	5 min
H_2O_2	2	50 ppt	5 min
CH_3OOH	2	50 ppt	5 min
HCHO	2	20 ppt	1 min
$OH/HO_2/RO_2$	2	0.01/0.1/0.2 ppt	1 min
SO_2	2	10 ppt	1 min
Speciated NMHC	2	5 ppt	5 min
Halocarbons	2	1-5 ppt	5 min
OVOC ($>C_1$)	2	5-20 ppt	5 min
N_2O	3	1 ppb	10 s
Aerosol size/number	2	10 nm-20 µm	1 min
Aerosol number CN/CCN	2	D>3 nm	10 s
Black carbon/light absorbing aerosol	2	100 ng/SCM	5 min
Aerosol composition (size resolved and bulk)	2	20 ppt	10 min
Multi-wavelength optical properties (absorp./scatter.)	3	--	1 s
Organic nitrates	3	5 ppt	5 min
Alcohols	3	20 ppt	5 min
Organic acids	3	20 ppt	5 min
Sulfuric acid	3	0.01 ppt	5 min
NO_y	3	30 ppt	10 s
HNO_4	3	5 ppt	10 s
HCN/RCN	3	20 ppt	5 min
Radionuclide (^{22}Rn, ^{7}Be, ^{210}Pb)	3	0.05-1 Bq/SCM	10 min
OCS	4	5 ppt	5 min

Single particle composition	4	D>50 nm	1 s
Remote measurements			
O_3 (nadir/zenith)	1	5 ppb	Z<500 m
Aerosol profiles	1	SR 1 at 1 μm	Z<100 m
Spectral actinic flux	2	10^{-5}/s (j_{uv})	10 s
Aerosol optical depth spectra	2	0.01	5 s
Solar spectral irradiance	2	Accuracy 1-3%	5 s
H_2O (nadir/zenith)	3	20 ppm	Z<500 m
Temperature	3	2 K	Z<500 m
Exploratory measurements			
NH_3	5-2	30 ppt	2 min
CO Lidar	5-2	20 ppb	Z<500 m
Real time NMHC/tracers	5-3	20 ppt	30 s
HNO_2	5-3	5 ppt	5 min
Meteorological/other measurements			
Meteorological Measurement System (u, v, w, T)	1	0.1%	1 s
Lightning/storm scope	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.

B. Overall mission plan and deployment sites

The first part (INTEX-B-Part I) will focus on MIRAGE-Mex objectives and conduct flights jointly with C-130. March is a month of choice because of enhanced outflow of pollution from Mexico city prior to the start of the wet season. Further there are fires in Central America that are transported in the northwesterly direction. Similarly the second part of this experiment (INTEX-B-Part II) will utilize both the DC-8 and C-130 to investigate the inflow of Asian pollution and April is a suitable period when this inflow is near its peak. During April the DLR Falcon will operate over the eastern Atlantic to explore the transport of both Asia and NA pollution to this region.

Figure 6 shows operational sites for INTEX-B and gives nominal flight tracks for the DC-8. Keeping in mind the logistical and science requirements the following operational sites are presently deemed most suitable:

NASA DC-8 (Houston, TX/March 1-31; Hilo, Hi/April 1-12; Anchorage, AK/April 13-30)
- NSF/NCAR C-130 (Tampico, MX/March 1-31; Seattle, WA/April 1-30)
- DLR Falcon-20 Oberpfaffenhofen, Germany/April 1-30)

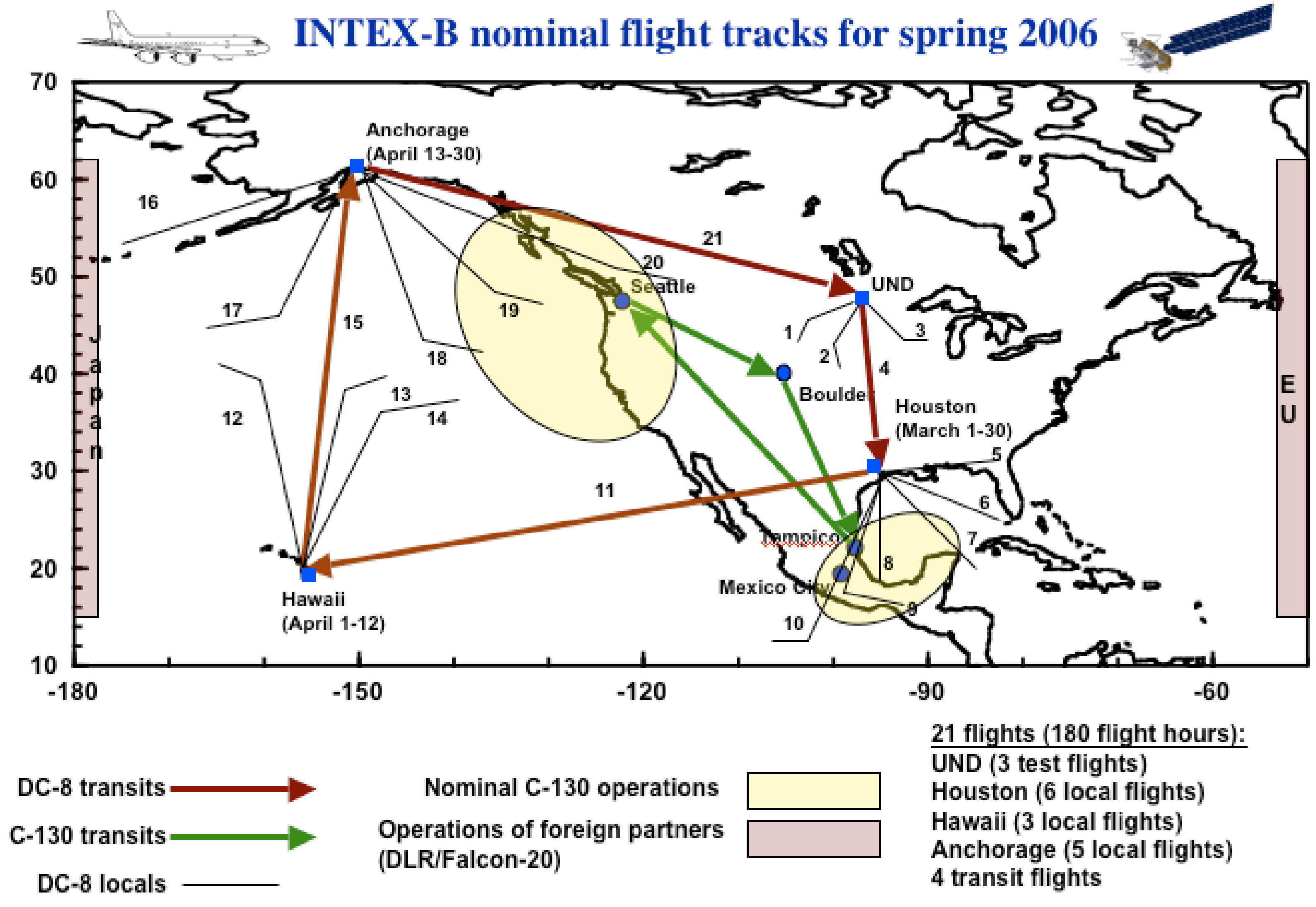


Figure 6: Nominal flight tracks for INTEX-B. DC-8 tracks are shown in solid black lines.

The C-130 operational area is also shown in Figure 6. The choice of these locations was dictated by meteorological analysis (Figures 1 and 4) and logistical constraints. During INTEX-B/Part 1 Houston is chosen for the DC-8 base as it meets all science and logistical objectives. From Houston the DC-8 can easily investigate MC air masses that have been previously sampled by the C-130. During INTEX-B/Part II, the preferred choices are Alaska and Anchorage for the DC-8 Seattle for the C-130. Such an operational base is most desirable as it allows extensive coverage over the Pacific and permits studies of pollution evolution that would not be possible if the DC-8 was co-located with the C-130 in Seattle, WA. We envision that a total of 180 flight hours will be available to perform a total of 20 flights (14 science/local, 3 science/transit, and 3 test flights). We anticipate that the C-130 will have a comparable number of flight hours available for this mission. The Falcon-20 is expected to participate only during Part II of INTEX-B and will have an estimated 50-80 flight hours.

C. Measurement strategy

INTEX-B/MIRAGE-mex/IMPACT effort will use a high altitude long-range aircraft (NASA DC-8; ceiling 12 km), a low altitude aircraft (NSF/NCAR C-130; ceiling 7 km), and a high altitude medium-range aircraft (DLR Falcon-20; ceiling 14 km) possibly augmented by more specialized aircraft. The DC-8 is the platform of choice for the task of large-scale chemical characterization and the C-130 is best suited for lower tropospheric and boundary layer studies including processes of exchange with the free troposphere. DLR will mostly operate over the eastern Atlantic and has the best capability to penetrate the stratosphere. All aircrafts will pursue targeted objectives with optimized observational priorities. Climatological analysis (Figures 1 and 4) suggests that the 4-week duration for each of the INTEX-B parts should allow sampling of 3-5 major Asian inflow and 5-7 Mexico City outflow events. Figures 7 and 8 gives examples of coordinated flights during Part 1 and Part 2 respectively where DC-8 and C-130 can jointly expand the scale of measurements and study the processes of evolution under a variety of conditions.

The following flight strategies are envisioned:

(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 (DC-8, C-130, and Falcon-20). This will involve characterization of the troposphere (0-12 km) over the eastern Pacific, parts of continental North America, the Gulf of Mexico, and the eastern Atlantic.

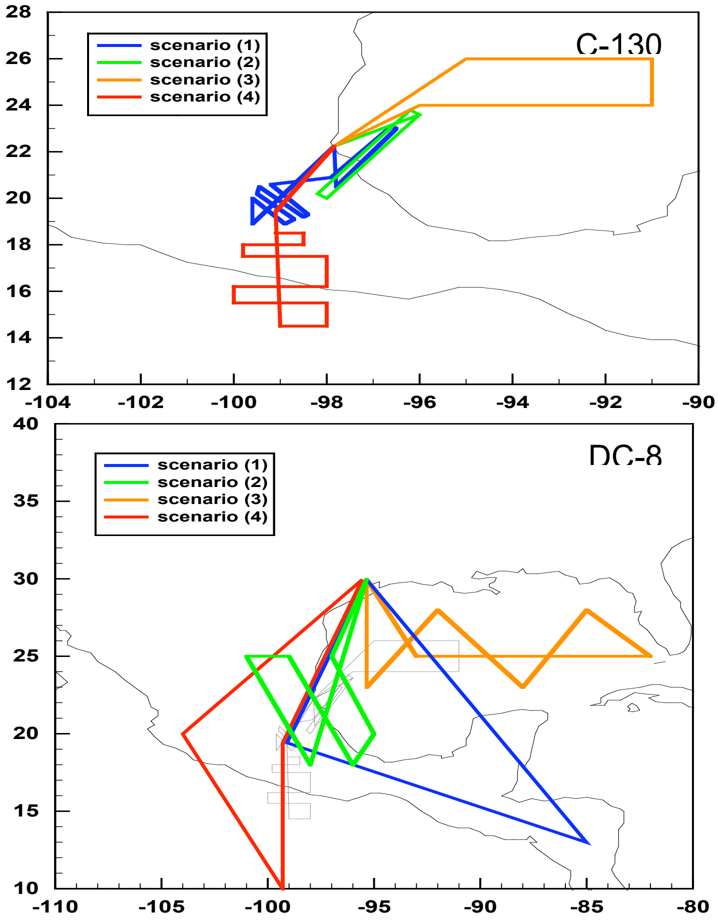


Figure 7: Examples of DC-8 and C-130 coordinated sampling of pollution outflow from Mexico City. Top Panel: C-130 flight scenarios taken from the MIRAGE Scientific Overview. Scenario (1) represents sampling of fresh outflow from Mexico City. Scenarios (2) and (3) represent sampling of aged outflow 1 to 3 days downstream. Scenario (4), represents sampling during a Norte event. Bottom Panel: Sample DC-8 flights coordinated with C-130. In each scenario, the initial stage of the flight is closely linked to the C-130 operation for the purpose of guidance and refinement of C-130 operations. The remainder of the flight allows for detailed sampling of the greater surrounding region.

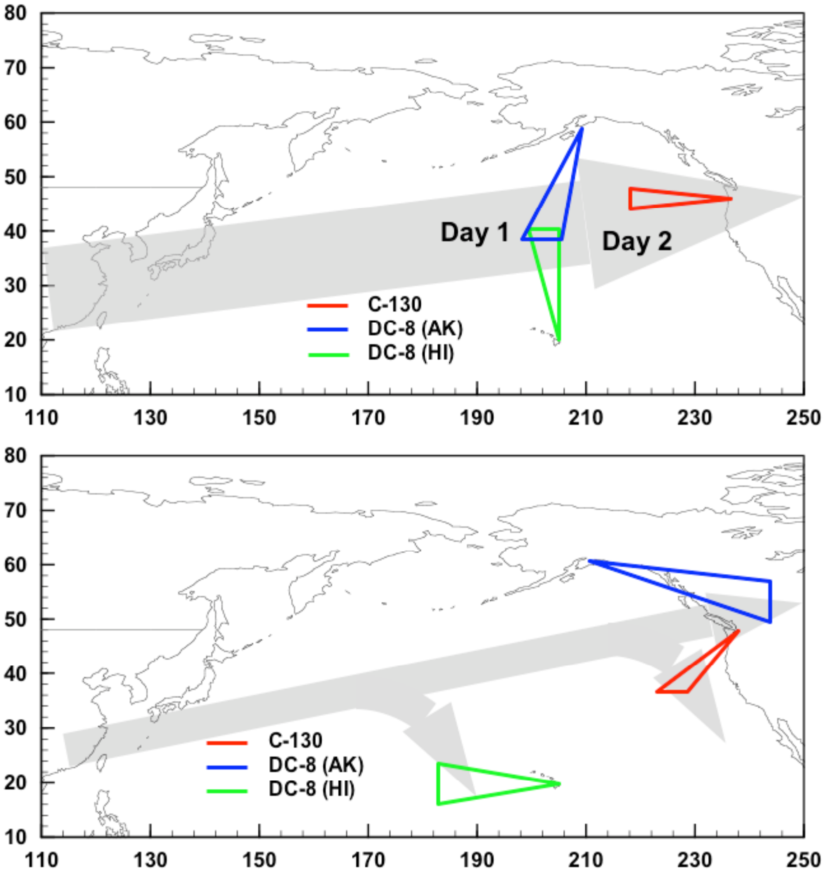


Figure 8: Examples of DC-8 (Base-Anchorage, AK) and C-130 (Base-Seattle, WA) coordinated sampling of Asian inflow to North America. Top Panel: Quasi-lagrangian sampling of trans-Pacific transport; Bottom Panel: Sampling the various branches of outflow to investigate comparative evolution;

(3) Intercontinental transport of Asian pollution plumes (DC-8, C-130, and Falcon-20). This will involve the interception of Asian pollution plumes during travel across the Pacific and the characterization of their layered structure. Activities over the western and mid-Pacific are anticipated in collaboration with Asian partners. Asian and/or North American pollution plumes reaching the eastern Atlantic will be sampled by the Falcon-20. It is expected that major dust storms would also occur and would be sampled.

(4) Large-scale continental outflow characterization (DC-8 and C-130). This will involve large-scale transects over the Pacific and the Gulf of Mexico, to characterize the ventilation of different source regions and through different pathways.

(5) Chemical aging. This will involve sampling of Asian outflow over the Pacific 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 Pacific by the DC-8 are intercepted and sampled again by the C-130 after several days. Similar studies involving sampling of Mexico City pollution and central American fires are also anticipated over the Gulf of Mexico.

(6) Satellite validation flights (DC-8 and other aircraft). During INTEX-A a large number of satellite under-flights were performed to test and validate the accuracy of satellite observations from MOPITT, AIRS, and SCIAMACHY (Figure 5). This philosophy of embedding validation flights within science flights will continue to prevail during INTEX-B. The INTEX-B 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, HCN and aerosol. Validation will involve vertical profiling from the boundary layer to the aircraft ceiling (12 km) at the precise locations and times of satellite overpass. In consultation with Aura investigators, additional flight profiles will be developed to benefit limb-scanning satellite instruments.

(7) Aerosol radiative effect flights. During INTEX-A a large number of flights were performed to study the direct and indirect effects of aerosols on radiation and climate. They were flown by the J31, making simultaneous measurements of optical depth spectra and solar radiative flux spectra, both of which extended from the ultraviolet through the visible and into the near infrared, so as to include most incident solar energy. Together they documented aerosol effects on solar radiation, both cloud-mediated (indirect) and cloud-free (direct). They also provided measurements essential to the INTEX goal of relating space-based observations to those from airborne and surface platforms, including the validation of satellite measurements of aerosols and water vapor. INTEX-B will require similar types of flights to address these continuing goals.

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APPENDIX 1: Relevant acronyms

AIRS: Atmospheric Infrared Sounder
CALIPSO: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CALIOP: Cloud-Aerosol Lidar with Orthogonal Polarization
CTM: Chemical Transport Model
DLR: Deutschen Zentrum für Luft- und Raumfahrt
IGAC: International Global Atmospheric Chemistry
IGBP: International Geosphere-Biosphere Program
INTEX-NA: Intercontinental Chemical Transport Experiment-North America
ITCT: Intercontinental Transport and Chemical Transformation
MIPAS: Michelson Interferometer for Passive Atmospheric Sounding
MLS: Microwave Limb Sounder
MIRAGE: Megacity Impacts on Regional and Global Environments-Mexico City
MOPITT: Measurement of Pollution in the Troposphere
MISR: Multiangle Imaging SpectroRadiometer
MODIS: Moderate Resolution Imaging Spectroradiometer
NA: North America
NCAR: National Center for Atmospheric Research
NOAA: National Oceanic and Atmospheric Administration
NSF: National Science Foundation
OMI: Ozone Monitoring Instrument
SCIAMACHY: Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
TES: Tropospheric Emission Spectrometer
TRACE: Transport and Chemistry Experiment