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Introduction to the SONEX (Subsonic Assessment Ozone and Nitrogen Oxides Experiment) and POLINAT-2 (Pollution from Aircraft Emissions in the North Atlantic Flight Corridor) Special Section

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Nitrogen Oxides and Ozone from Subsonic Aviation. Previous Campaigns.

Emissions of atmospheric species from the engines of subsonic aircraft at cruise altitude (roughly, above 7 km) are of concern to scientists, the aviation industry and policymakers for two reasons. First, water vapor, soot and sulfur oxides, and related heterogeneous processes, may modify clouds and aerosols enough to perturb radiative forcing in the UT/LS (upper troposphere/lower stratosphere; acronyms are given in an Appendix). A discussion of these phenomena appears in Chapter 3 of the IPCC Aviation Assessment [1999]. An airborne campaign conducted to evaluate aviation effects on contrail, cirrus and cloud formation, is described in *Geophysical Research Letters* (vol. 25, nos. 8-10, 1998).

The second concern arises from subsonic aircraft emissions of nitrogen oxides ($NO+NO_2 = NO_x$), CO, and hydrocarbons. These species may add to the background mixture of photochemically reactive species that form ozone. In the UT/LS, ozone is a highly effective greenhouse gas. The impacts of subsonic aircraft emissions on tropospheric NO_x and ozone budgets have been studied with models that focus on UT chemistry [e.g. see discussions of individual models in Brasseur et al., 1998; Friedl et al., 1997; IPCC, 1999]. Depending on the model used, projected increases in the global subsonic aircraft fleet from 1992 to 2015 will lead to a 50-100 pptv increase in UT/LS NO_x at 12 km (compared to 50-150 pptv background) in northern hemisphere midlatitudes. The corresponding 12-km ozone increase is 7-11 ppbv, or 5-10% (Chapter 4 in IPCC, 1999).

Two major sources of uncertainties in model estimates of aviation effects are: (1) the often limited degree to which global models - the scale required to evaluate aircraft emissions - realistically simulate atmospheric transport and other physical processes; (2) limited UT/LS observations of trace gases with which to evaluate model performance. In response to the latter deficiency, a number of airborne campaigns aimed at elucidating the effect of aircraft on atmospheric nitrogen oxides and ozone were performed between 1990 and 1996 (see descriptions in Friedl et al., 1997; Brasseur et al., 1998).

Several preliminary research experiments [Schumann *et al., this issue*] focused on measurements of particulate emissions, NO and ozone over Europe and the eastern Atlantic between 30 and 60N latitude. In this heavily traveled airway, perturbations due to relatively fresh exhaust were observed, including the buildup of aircraft-derived NO_x over the eastern Atlantic under favorable meteorological conditions [Schlager et al., 1997; *this issue*]. An experimental approach that complements specialized airborne missions uses more routine data collection to build a climatology for statistical analysis of trace gases in corridor regions and to determine the natural variability of the atmosphere. For example, the NOXAR campaigns with a commercial Boeing-747 measuring NO, NO_2 and ozone over standard airways between Switzerland and the United States [Brunner et al., 1998; Jeker et al., *this issue*] found the highest NO_x off eastern North America, apparently due to continental pollution and lightning overlying aircraft emissions. The MOZAIC climatology of ozone, temperature and water vapor measurements was amassed using five in-service Airbus jetliners to collect global data along a wide range of traffic routes [see the *Journal of Geophysical Research,* Vol. 103, 20 October 1998 issue and Cho et al., 1999a]. Nitrogen oxide measurements are being made on 1999-2000 MOZAIC follow-on flights (H. Smit and A. Marenco, Personal Communication, 1999).

Goals and Mission Strategies of SONEX and POLINAT-2 (1997).

The SONEX and POLINAT-2 campaigns described in this Special Section of the *Journal of Geophysical Research* were strategically designed to fill in continuing data gaps in the north Atlantic flight corridor (NAFC) and to address questions about nitrogen oxides and ozone not resolved by earlier research campaigns in this critical region. Although the experiments built upon previous work, SONEX and POLINAT-2 were distinguished from earlier missions that studied UT/LS nitrogen oxides and ozone in four aspects.

o First, by combining SONEX and POLINAT-2, a campaign was assembled to give full longituinal coverage over the Atlantic between 30 and 60N (Plate 1). The POLINAT-2 DLR Falcon-20 aircraft (Mission Scientist H. P. Schlager) sampled in the eastern Atlantic, with three flights from Ireland closely coordinated with the SONEX DC-8 (Mission Scientists A. M. Thompson and H. B. Singh). The DC-8 also sampled south from the Azores and at the western end of the NAFC, from Bangor, Maine (US) - in addition to cross-US transits to and from its California home base. There were 24 trans-Atlantic NOXAR B-747 flight days during combined SONEX/POLINAT-2 operations. Close encounters of the B-747 occurred during flights on 28 September (Falcon 20) and 9 November (DC-8). The POLINAT Falcon flew briefly with ACSOE (similar payload to the Hercules) at the Azores [Schumann et al., *this issue*]. From Ireland, the Falcon 20 coordinated one Lagrangian flight with the NOAA P-3 operating as part of NARE from its September 1997 location at St John's, Newfoundland.

o Second, similar payloads were selected for the SONEX DC-8 and POLINAT-2 Falcon 20 (Table 1), with key instrumentation deliberately duplicated on the two platforms. This permitted full Atlantic coverage of many constituents and enabled comparison of selected Falcon and DC-8 instruments during close formation flights in October 1997 [Wohlfrom et al., 1999; Talbot et al., 1999; Miller et al., *this issue*]. The DC-8 carried three instruments to measure nitric acid, a key reactive nitrogen constituent that is an ongoing challenge [see for example, Gregory *et al.* 1990, or Kliner *et al.* 1997].

o Third, as illustrated in the following section, SONEX/POLINAT-2 supplemented climatology and routine forecasts [Fuelberg et al., *this issue*] with state-of-the art model products [Schlager et al., 1999] and satellite data to plan individual flights during deployment.

o Fourth, newly developed instrumentation and the payload size of the DC-8 research aircraft meant that a large number of chemical species and physical variables could be measured. Aerosol physical and chemical properties, nearly complete cycles of odd hydrogen, reactive nitrogen, hydrocarbons and oxygenated intermediates [Singh et al., *this issue*] were measured aboard the DC-8, along with ozone. The DC-8 also carried turbulence instrumentation and an instrument that gives a 2-dimensional view of ozone and coarse aerosols [Grant et al., *this issue*].

The diverse measurement capabilities of SONEX/POLINAT-2 allowed the missions to address scientific issues more comprehensively than previous north Atlantic missions. These issues, with specific questions rephrased from the mission overview papers [Singh et al., 1999; Schumann et al., *this issue*], appear in Table 2. For additional background on SONEX and associated POLINAT-2 flights, the reader is referred to Singh et al (1999; STS in Table 2). POLINAT-2 is one of two experiments for which background information appears in Schumann et al. [*this issue*]. Further details on mission planning, forecasts, model products and flight summaries during deployment appear on the homepages: telsci.arc.nasa.gov/~sonex and www.pa.op.dlr.de/polinat/.

Flight Strategies, Operations and Coordination in SONEX/POLINAT-2

The scientific issues addressed by SONEX/POLINAT-2 led to an overall mission design that emphasized regional sampling during survey and transit flights, with a specific goal of assembling observations of UT/LS ozone, ozone precursors and tracers across regions of high/low air traffic and high/low continental influence. Major staging locations were selected to allow targeted sampling for various NO_x sources and to perform sampling in the same air mass for instrument comparisons. To accomplish the latter objective under conditions of fresh aircraft exhaust (higher concentrations), operations were required under radar control at either end of the OTS (Organized Track System) that is re-positioned daily within the NAFC. This consideration and other logistical requirements led to the selection of Shannon, Ireland (52°N, 10°W) and Bangor, Maine (45°N, 68°W) as the staging locations for

SONEX/POLINAT-2.

The fractional aircraft contribution to north Atlantic NO_x is highest in winter [Brasseur et al., 1996], at which time concentrations of some free radical levels could be too low for reliable measurement. Early-mid summer could be so high in convective activity, ie surface pollution transport to the UT, that aircraft signatures could be hard to detect. Late summer has moderately active photochemistry, as well as periods with and without deep convection. The combined SONEX/POLINAT-2 mission was scheduled for August-September 1997 to optimize encounters with a variety of NO_x sources in the NAFC. However, mechanical problems with the DC-8 caused operations to shift into early-mid autumn. This reduced the originally planned schedule of co-sampling between SONEX and POLINAT-2 to three flights and eliminated close coordination between the SONEX DC-8 and NOAA P-3 over eastern North America during NARE-97.

Table 3 shows the POLINAT-2 flights performed during the period 18 September-23 October 1997 (Schumann et al., *this issue*), with SONEX deployment 13 October -12 November 1997 (Thompson et al., 1999). Solar insolation in the middle of SONEX was 1/3 of what it would have been in early September but photochemistry, e.g. HO_x radicals, remained well above detection limit [Brune et al., 1999; Faloona et al., *this issue*]. Besides photochemical activity, a second concern about a mid-Fall SONEX deployment was tropopause height. A low tropopause would have put more DC-8 sampling into the lower stratosphere relative to the upper troposphere. However, the tropopause was higher than climatology during SONEX [Fuelberg et al., *this issue*] and the typical potential vorticity encountered by the DC-8 was anomalously low [Thompson et al., 1999].

Plate 2 shows how flights were coordinated during SONEX/POLINAT-2. The westbound OTS on 20 October 1997 in Plate 2a was a target for one of three flights that the DC-8 and Falcon 20 planned and carried out together from Shannon. The Falcon 20 followed the DC-8 approximately one hour later, stopping and refueling in the Canary Islands before returning to Ireland. Coordination between the SONEX DC-8 and the POLINAT-2/NOXAR B-747 flying in the OTS (Plate 2b) took place when the Swissair commercial airliner headed toward North America on 9 November 1997. The B-747 sampled within 15 minutes of the DC-8 at the same location.

The overall objective of the 20 October 1997 flights (Plate 2a) was a survey south of the NAFC. To refine the flight path with respect to various NOx sources, model output and specialized meteorological fields supplemented the OTS in flight planning. Plate 3a shows a cross-section of potential vorticity vs time, with the DC-8 flight position superimposed. The high pv values predicted near takeoff and landing were confirmed by samples of stratospheric air in those regions (47-50N). Figures 3b and 3c show two types of model products designed to show accumulated aircraft impacts. In Plate 3b dynamical fields from a mesoscale model used to transport NO_x from aircraft show a plume of highest aircraft influence over southern Ireland near the Shannon takeoff point [Flatøy and Schlager, 2000]. Plate 3c uses a grid of air parcels run backwards with a trajectory model for 5 days to estimate number of hours spent in regions of aircraft traffic. Both the tracer fields and the trajectory model predicted high aircraft impact during the flight from Shannon toward Spain. The trajectory mapping approach was also used to assess the likelihood of encountering air with a history of convection (Plate 3d) and lightning. Flight planning performance for the 20 October 1997 flights was evaluated by comparing observations with model products like those of Plates 3b-d and with output from a coupled chemistry-transport model [Meijer et al., *this issue*].

SONEX/POLINAT-2 Publications

Table 2 lists all papers published using SONEX/POLINAT-2 data arranged by the major scientific issues of the two experiments. In addition to the 20 papers of the Special Section of the *Journal of Geophysical Research* that follows, eight highlights papers appeared in the 15 October 1999 issue of *Geophysical Research Letters* (vol. 26, no. 20). Five additional papers have been published or will shortly appear in these two journals.

For further details of the individual missions, and how the papers correspond to each scientific issue, the reader should refer to the overview articles. Singh et al (1999) discuss strategic issues and the main results of SONEX and coupled POLINAT-2 activity, with an emphasis on the accompanying papers in *Geophysical Research Letters* (vol. 26, no. 20). Schumann et al (*this issue*) discuss scientific questions and contributions from POLINAT-1 and POLINAT-2, along with many references and background information from other aviation-related experiments.

The strategic planning of SONEX/POLINAT-2 assured that these missions successfully addressed most of the scientific issues they set out to investigate. However, the ultimate goal of determining aviation impacts on nitrogen oxides and ozone awaits incorporation of data into coupled chemistry-transport models and the ongoing evaluation of both models and multiple observations in the international assessment process.

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Acronyms

ACSOE = Atmospheric Chemistry Studies in the Oceanic Environment
AERONOX = EC Programme in Environmental Protection
DLR = Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
EC = European Commission
IPCC = Intergovernmental Panel on Climate Change
MOZAIC = Measurements of Ozone Aboard In-service Aircraft
NARE = North Atlantic Regional Experiment (an IGAC Project)
NAFC = North Atlantic Flight Corridor
NOXAR = Nitrogen OXides along Air Routes
OTS = Organized Track System
POLINAT = Pollution from Aircraft Emissions in the North Atlantic Corridor
SONEX = SASS [Subsonic Assessment] Ozone and Nitrogen Experiment
UT = Upper Troposphere; UT/LS = UT/Lower Stratosphere

Table 1: SONEX/POLINAT-2 instrument payload*

Mission	Measured parameters	Principal investigators	Organization	Measurement principle	Detection limit/response (nominal accuracy)
SONEX/DC-8	O_3	G. Gregory	NASA Langley	Chemiluminescence	1 ppb/5s (±5%)
	NO/NO_y	Y. Kondo	Nagoya Univ.	Chemiluminescence	5 ppt/5s (±15%/20%)
	PANs/$RONO_2$	H. Singh	NASA Ames	GC/ECD	2 ppt/120s (±20%)
	Acetone/methanol			GC/RGD	15 ppt/120s (±25%)
	HNO_3	R. Talbot	U. of New	Mist chamber/IC	10 ppt/300s (±25%)
	Aerosols/org. acids		Hampshire		5 ppt/1200s (±25%)
	$HNO_3/SO_2/HCN$	A. Viggiano	Air Force Lab	CIMS	10 ppt/100s (±30%)
	HNO_3/NO_2	J. Podolske	NASA Ames	TDL/open path	10 ppt/60s (±30%)
	OH/HO_2	W. Brune	Penn State U.	LIF	0.03ppt/100s (±40%)
	H_2O_2, CH_3OOH,	B. Heikes	U. of Rhode	HPLC derivatives	20 ppt/150s (±30%)
	HCHO		Island		
	NMHC/ $RONO_2$	D. Blake	U. C. Irvine	Grab sample/GC	1-5 ppt/100s (±2-10%)
	$CO/CH_4/N_2O$	G. Sachse	NASA Langley	TDL spectrometer	1 ppb/1s (±2%)
	H_2O			TDL spectrometer	1 ppm/1s (±5%)
	CN/CN-heated	B. Anderson	NASA Langley	Counters	1 cm^{-3}/5s (±20-30%)
	CO_2	B. Anderson	NASA Langley	IR absorption	0.1 ppm/1s (±0.1%)
	CN/CN-heated	R. Pueschel	NASA Ame	Counters	1 cm^{-3}/5s (±20-30%)
	Soot	R. Pueschel	NASA Ames	Impacters	----/600s (±15%)
	Photolysis rates	J. Shetter	NCAR	Spec. radiometers	10^{-8} s/15s (±15%)
	Remote O_3/aerosol	E. Browell	NASA Langley	UV Lidar	----/60s (±10%)
	Remote T	M. Mahoney	JPL	Microwave	----/60s (±0.5-2°K)
	T,p,u,v,w	P. Bui	NASA Ames	Met. System	----/1s (±0.2-4%)
POLINAT-2/ FALCON-20	O_3	H. Schlager	DLR	UV-absorption	1 ppb/5s (±5%)
	$NO/NO_2/NO_y$			Chemiluminescence	5 ppt/5s (±15%/25%/20%)
	CO_2			IR-absorption	±0.5 ppm (±0.1%)
	HNO_3/SO_2/Acetone	F. Arnold	MPI-K	CIMS	10 ppt/100s (±40%)
	H_2SO_4				0.1 ppt/100s (±40%)
	NMHC	F. Slemr	IFU	Grab sample/GC	5 ppt/100s (±8-20%)
	CO			VUV-fluorescence	1 ppb/1s (±5%)
	$j(NO_2)$			Actinometery	10^{-8} s/15s (±15%)
	CN/CN-heated	P. Whitefield	UMR	CN Counters	1 cm^{-3}/5s (±15-20%)
	Aerosol size			EAC	---- (±20-30%)
	H_2O	J. Ovarlez	CNRS-LMD	Frost point/cryogenic	1 ppm/1s (±5%)
POLINAT-2/ B-747	NO/NO_2	H. Staehelin	ETH	Chemiluminescence	5 ppt/5s (±15%/30%)
	O_3				1 ppb/5s (±5%)

*Adapted from Singh et al. [1999] and Schumann et al., [this issue].

Table 2. **Major Issues addressed by SONEX/POLINAT-2 Experiments and Relevant Publications (current to 1 Jan. 2000)**

Issue	SONEX, Reference* STS	POLINAT Reference Schumann et al, *this issue*	Questions, Publications
Measurement reliability, reactive nitrogen closure, instrument comparisons	Questions 1, 2	Section 4.7	How did DC-8, Falcon 20 and NOXAR (where applicable) measurements of NO, total reactive nitrogen (NO_y), ozone and other tracers compare to one another? Did NO_y equal the sum of the individually measured reactive nitrogen species? How did water vapor and HO_x measurements compare to model predictions? Brune et al., 1999; Jaeglé et al., 1999; Talbot et al., 1999; Wohlfrom et al., 1999 This issue: Faloona et al., Miller et al., Overlaz et al., Paladino et al., Vay et al.
Near-field exhaust encounters and mixing. Reactive nitrogen, particulate emissions.	—	Sections 4.1 - 4.4	What are the characteristics of particles and NO in fresh aircraft exhaust? Is the NAFC a distinct atmospheric feature? Anderson et al., 1999; Ferry et al., 1999; Schlager et al., 1999; Thompson et al., 1999; Wang et al., 2000 This issue: Dibb et al., Jeker et al., Paladino et al., Pueschel et al., Simpson et al., Vay et al., Ziereis et al.
Evaluation of aircraft particulate NO_x sources.	5	Section 4.5	Is there a unique tracer for NO_x from aircraft? Can the aircraft contribution to NO_x be quantified relative to contributions from surface pollution, lightning, the stratosphere? Kondo et al., 1999; Liu et al., 1999; Schlager et al., 1999; Thompson et al., 1999. This issue: Allen et al.; Bieberbach et al.; Hannan et al.; Jeker et al.; Koike et al.; Meijer et al.; Ziereis et al.

Table 2. Major Issues addressed by SONEX/POLINAT-2 Experiments and Relevant Publications (current to 1 Jan. 2000) cont'd.

Issue	SONEX, Reference* STS	POLINAT Reference Schumann et al, *this issue*	Questions, Publications
Measurements of non-nitrogen, non-particulate tracers, reactive hydrogen.	3	Section 4.6	Based on hydrogen oxide measurements (HO_x=HO + HO_2), what is the photochemical lifetime of UT/LS NO_x? Do photochemical theory and observations of HO_x and peroxides agree? What are distributions of ozone, CO, hydrocarbons, water vapor, oxygenated intermediates? Brune et al., 1999; Jaeglé et al., 1999; Wohlfrom et al., 1999 This issue: Faloona et al.; Fuelberg et al.; Grant et al.; Jaeglé et al., Simpson et al.; Singh et al.; Vay et al.
Dynamic interactions, variability.	—	Section 4.10	What is the interaction of dynamical effects - convection, stratosphere-troposphere exchange, latitudinal mixing on tracer distributions in the NAFC? Cho et al., 1999b; Schlager et al., 1999; Thompson et al., 1999; Wang et al., 2000 This issue: Allen et al.; Bieberbach et al.; Fuelberg et al., Grant et al., Hannan et al.; Meijer et al.
Aircraft Impacts on Ozone. Agreement of models with observations.	4,6	Sections 4.8, 4.9	What was the effect of aircraft NO_x on ozone formation in the NAFC during the SONEX/POLINAT-2 observing period? Brune et al., 1999; Jaeglé et al., 1999. This issue: Jaeglé et al.; Meijer et al.

* STS = Singh et al., 1999

Table 3. POLINAT2 and SONEX Flights, 1997
(SNN = Shannon, Ireland; BGR = Bangor, Maine, US)

POLINAT-2 Flight & Date	Purpose	SONEX Flight & Date	Purpose
1, 19 Sept.	SNN, No. corridor survey		
2, 3, 21 Sept.	SNN to Azores and return, ACSOE/C-130 comparison		
4, 24 Sept.	SNN, contrails, compare MOZAIC		
5, 26 Sept.	SNN local; NARE/P-3 Lagrangian		
6, 7, 28 Sept.	SNN No. corridor survey; compare NOXAR B-747; NARE P-3 Lagrangian		
		3*, 13 Oct.	Moffett Field, CA to Bangor, ME, in-track
8, 9, 14 Oct.	SNN so. survey to Tenerife and return		
		4, 15 Oct.	In-track, BGR to SNN
10, 18 Oct.	SNN cross-track, SONEX DC-8 co-fly	5, 18 Oct.	SNN Cross-track #1 Falcon 20 co-fly
11, 12, 20 Oct.	SNN southern survey SONEX DC-8	6, 20 Oct.	SNN southern survey, Falcon 20 coordinated
13, 23 Oct.	SNN cross-track SONEX DC-8 co-fly	7, 23 Oct.	SNN Cross-track #2 Falcon 20 co-fly
		8, 25 Oct.	SNN No. survey, stratospheric
		9, 28 Oct.	SNN to Azores, UT leg, in-track
		10, 29 Oct.	Azores, southern survey
		11, 31 Oct.	Azores to BGR, continental outflow
		12, 3 Nov.	BGR, convection, lightning
		13, 5 Nov.	BGR Coastal survey
		14, 9 Nov.	BGR Cross-track with convection, lightning; compare NOXAR B-747
		15, 10 Nov.	BGR northern survey
		16, 12 Nov.	BGR to Moffett Field, CA, in-track

Notes: Track refers to flight in US standard airway or in designated trans-Atlantic organized track. Corridor is defined as broader region of high air traffic as indicated by climatological aircraft emissions databases. * SONEX Flights 1 and 2 were instrument test flights off California coast.

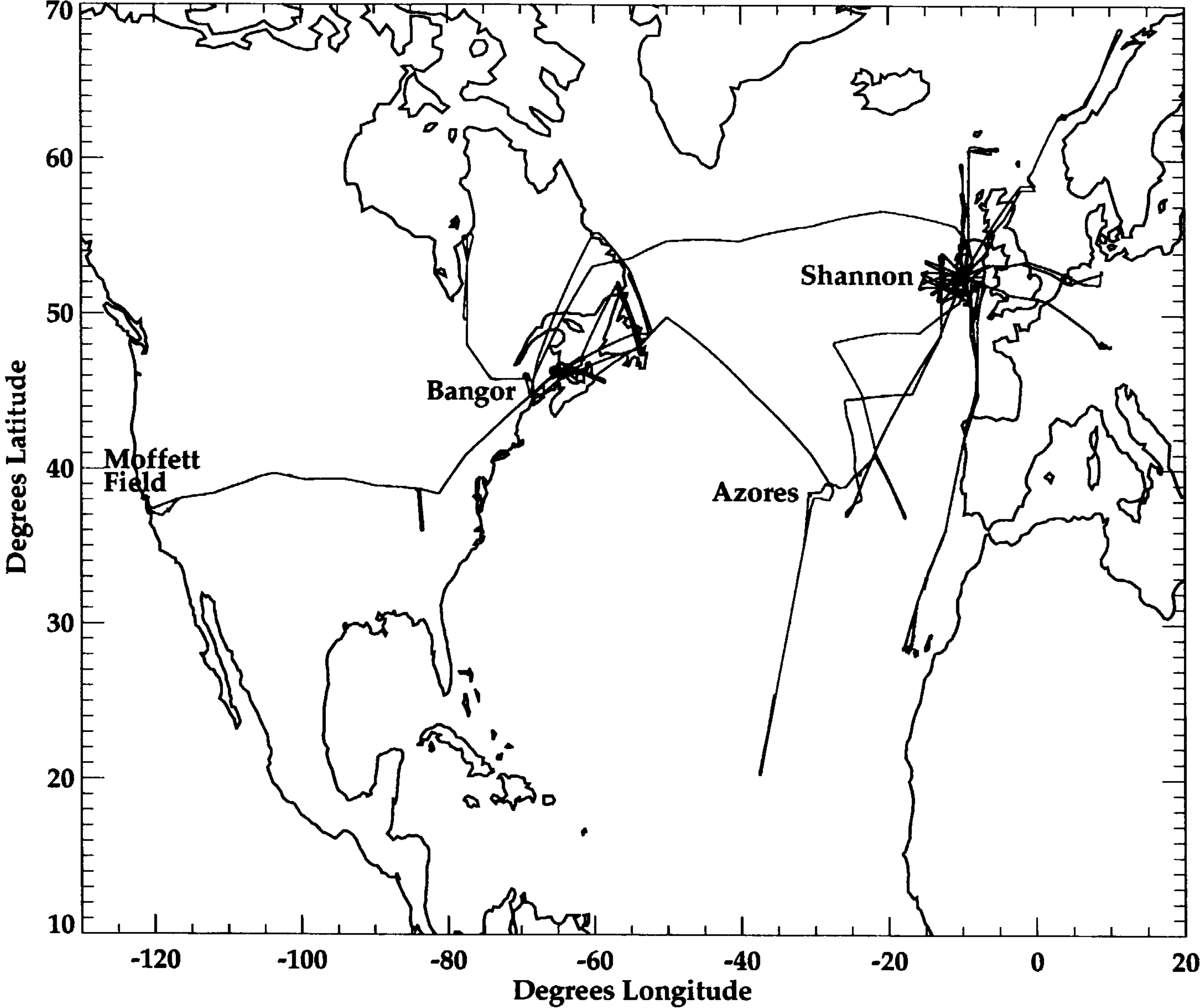
Plate Captions.

Plate 1. Flight tracks for SONEX DC-8 and POLINAT-2 Falcon 20 operations during the period 19 September to 12 November 1997. Individual flights are listed in Table 3. The region of greatest trans-Atlantic air traffic is between 40N and 60N. For NOXAR B-747 flights during the SONEX/POLINAT-2 period, see Schumann et al [*this issue*]. The SONEX-NOXAR coordination of 9 November 1997 is shown in Plate 2b.

Plate 2. (a) OTS for 20 October 1997, with coordinated sampling tracks of the SONEX DC-8 and POLINAT-2 Falcon 20 southern survey flights from Shannon, Ireland. (b) OTS for 9 November 1997. NOXAR B-747, traveling in Lane F, sampled within 15 minutes of SONEX DC-8 (Flight 14).

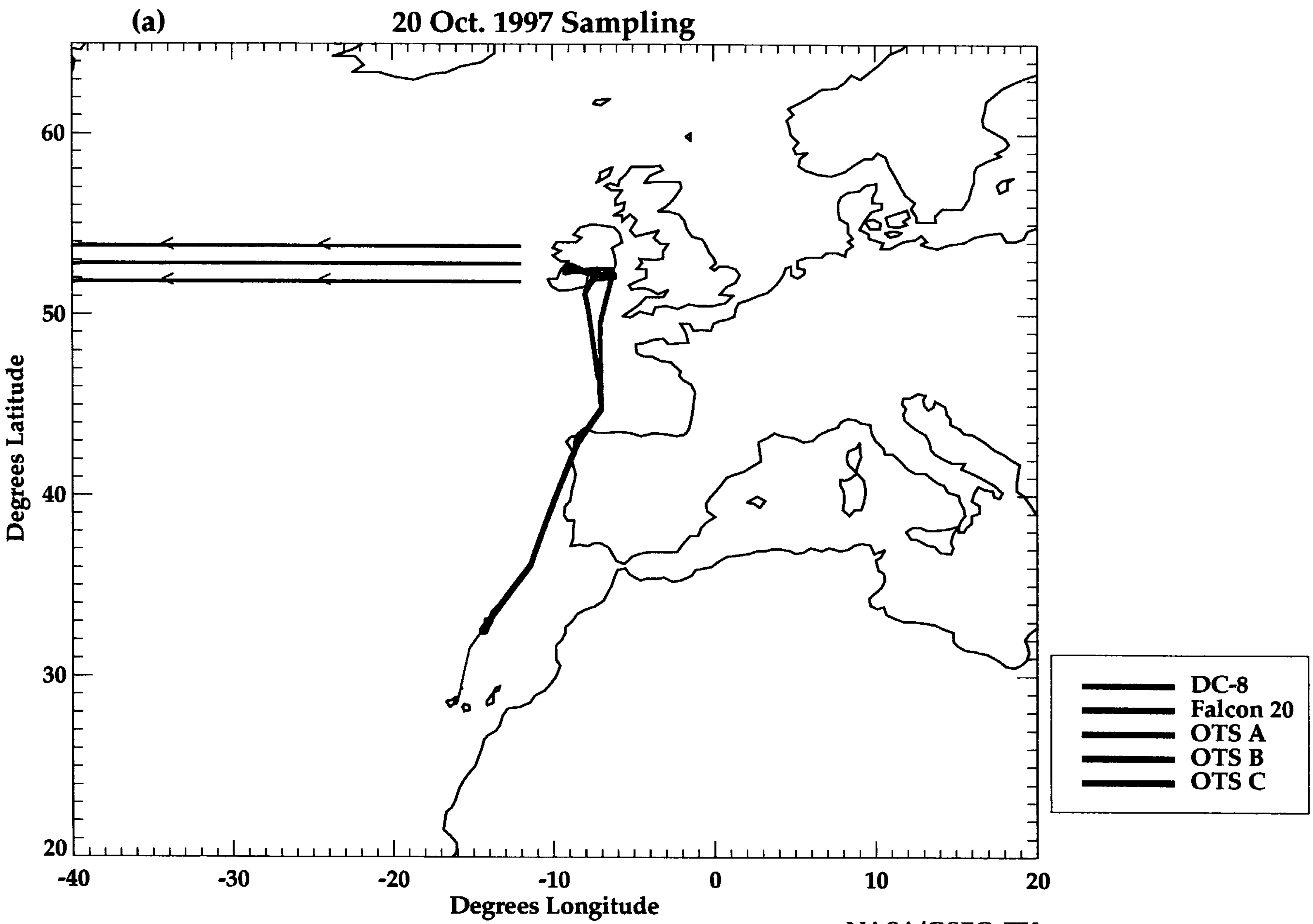
Plate 3. Examples of specialized meteorological products used in day-to-day SONEX/POLINAT-2 flight planning. Illustrations are for 20 October 1997 flights. (a) "Curtain plot" of modified Ertel's potential vorticity, with potential temperature and geopotential height superimposed, along DC-8 flight track depicted in Plate 2a. Post-mission analysis from the Goddard Data Assimilation Model is shown. During deployment, plots based on 48-hour forecast were used. (b) Tracer model output, showing distribution of NO_x (in ppbv) from aircraft emissions, predicted at 239 hPa (from the University of Bergen mesoscale model, for which forecasts were posted on the POLINAT-2 homepage throughout the field campaign; Schlager et al.,1999). (c) Aircraft exposure product from NASA/Goddard Space Flight Center, as used during SONEX. Starting from each point in the 1x1 deg grid, air parcels are followed backward with an isentropic trajectory model for 5 days (350K surface shown). Exposure times are the number of hours in that period that the air parcels overlie climatological aircraft corridor regions. Winds used in the Goddard isentropic trajectory model [Schoeberl and Newman, 1995] are derived from Goddard Data Assimilation Model. As for (a), 48-hour forecast winds were used during SONEX deployment; (d) Convective influence product from NASA/Ames Research Center. Exposure to convective clouds is determined using geostationary satellite imagery (GOES or METEOSAT) acquired every 15 minutes during the mission. Trajectories are used as in (c) except for the weighting function for time spent over deep convective clouds. Identification of convection intersecting 335K trajectories is based on cloud-top brightness temperatures. Reference for (c) and (d) is A. M. Thompson, L. Pfister, L. C. Sparling, T. L. Kuscera, L. R. Lait, K. E. Pickering, Y. Kondo, M. Koike, and H. B. Selkirk, SONEX synthesis based on flight planning trajectory models and tracer statistics, *unpublished manuscript.*

Flight Tracks for SONEX (DC-8) & POLINAT-2 (Falcon)



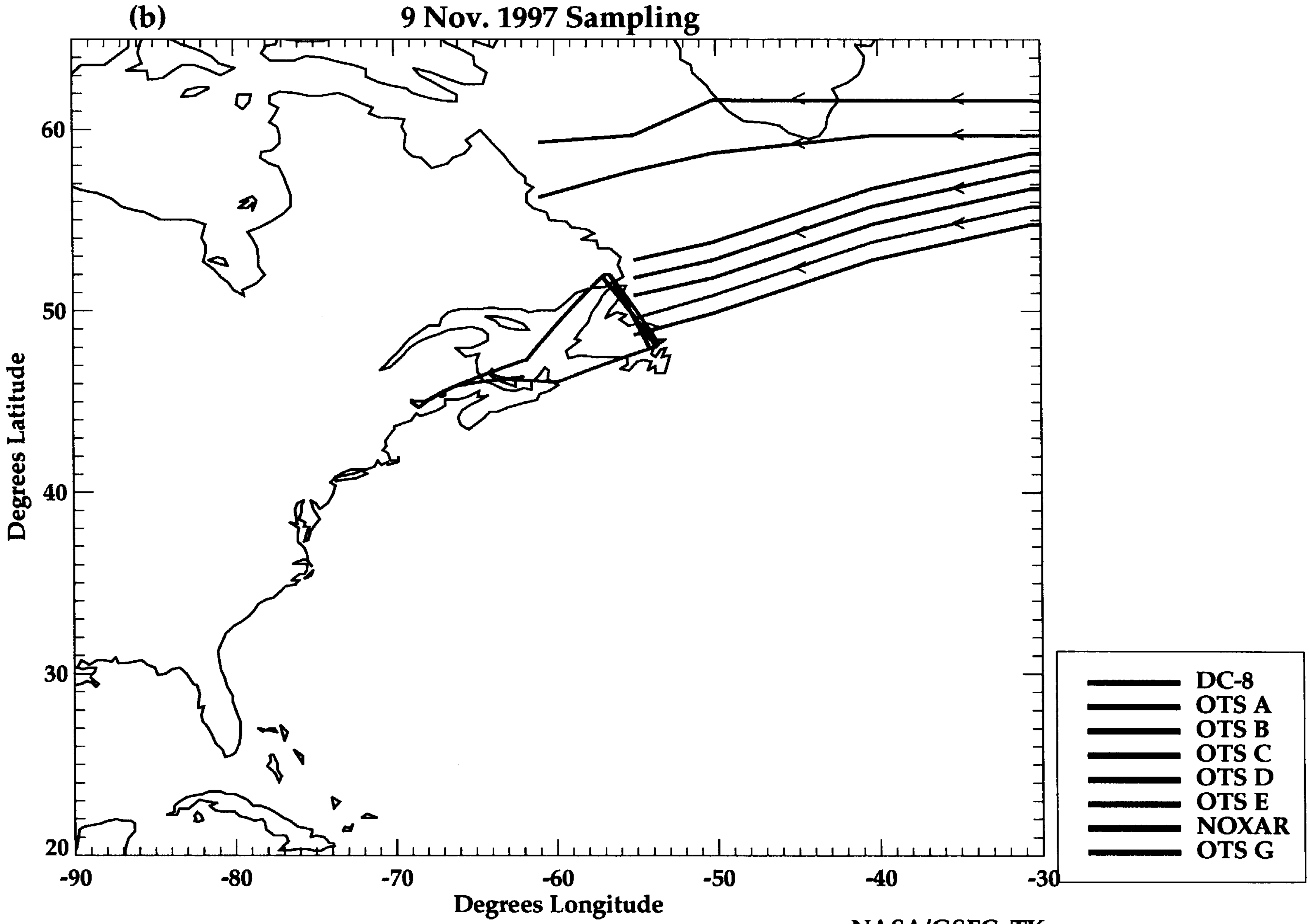
NASA/GSFC, TK

PLATE 1



NASA/GSFC, TK

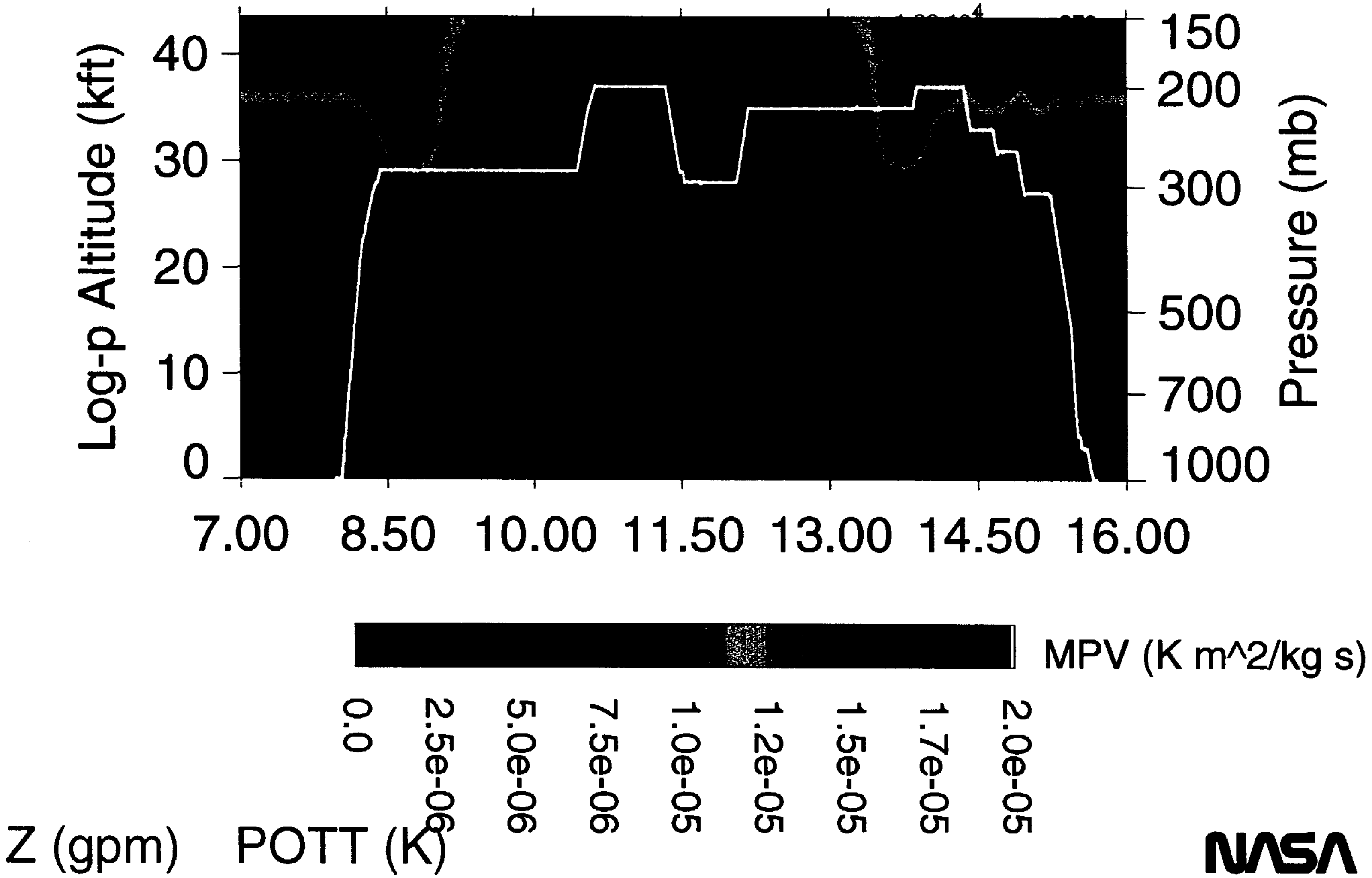
PLATE 2a



NASA/GSFC, TK

PLATE 2b

12 UTC on 20 October, 1997



GSFC

PLATE 3a

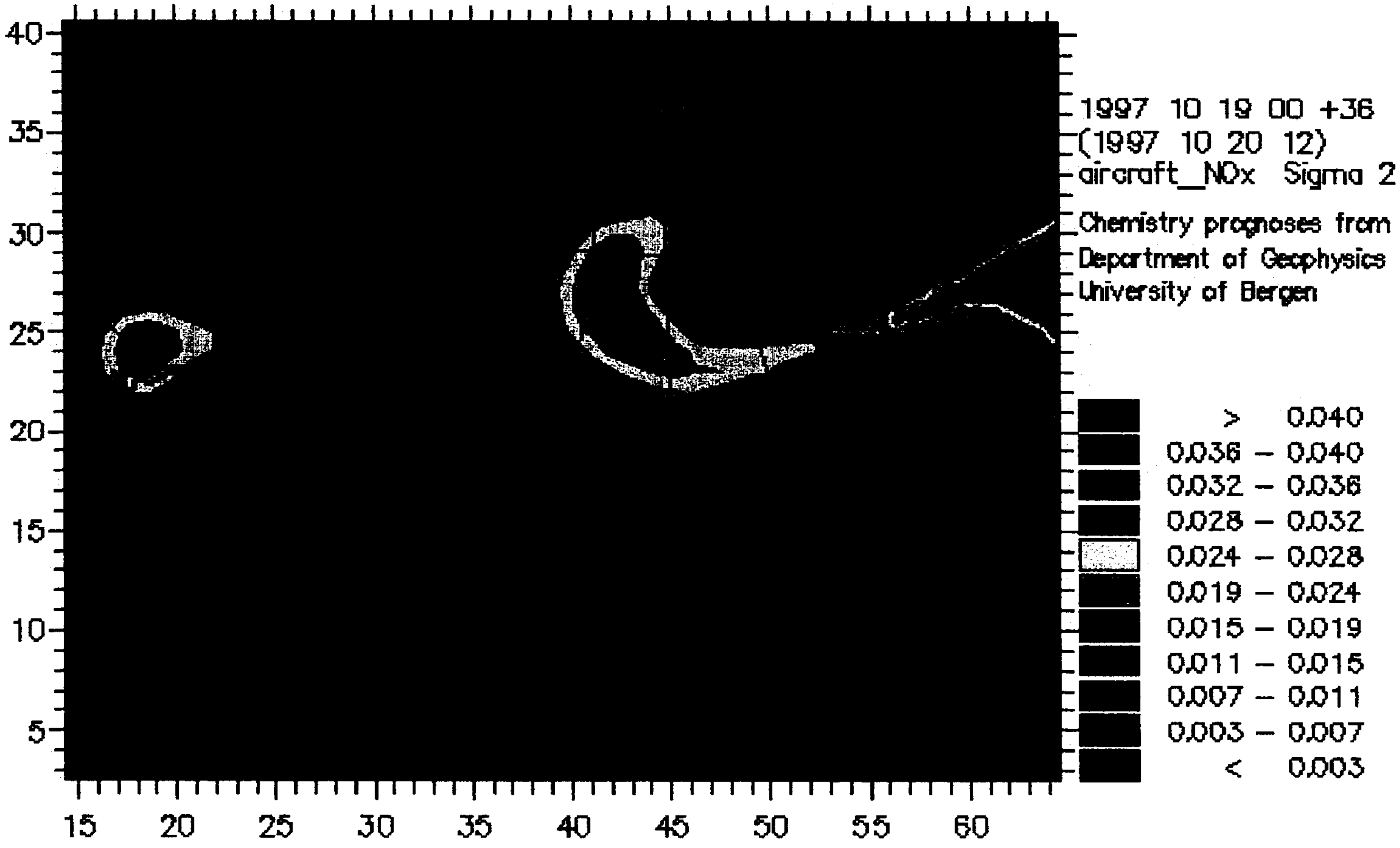
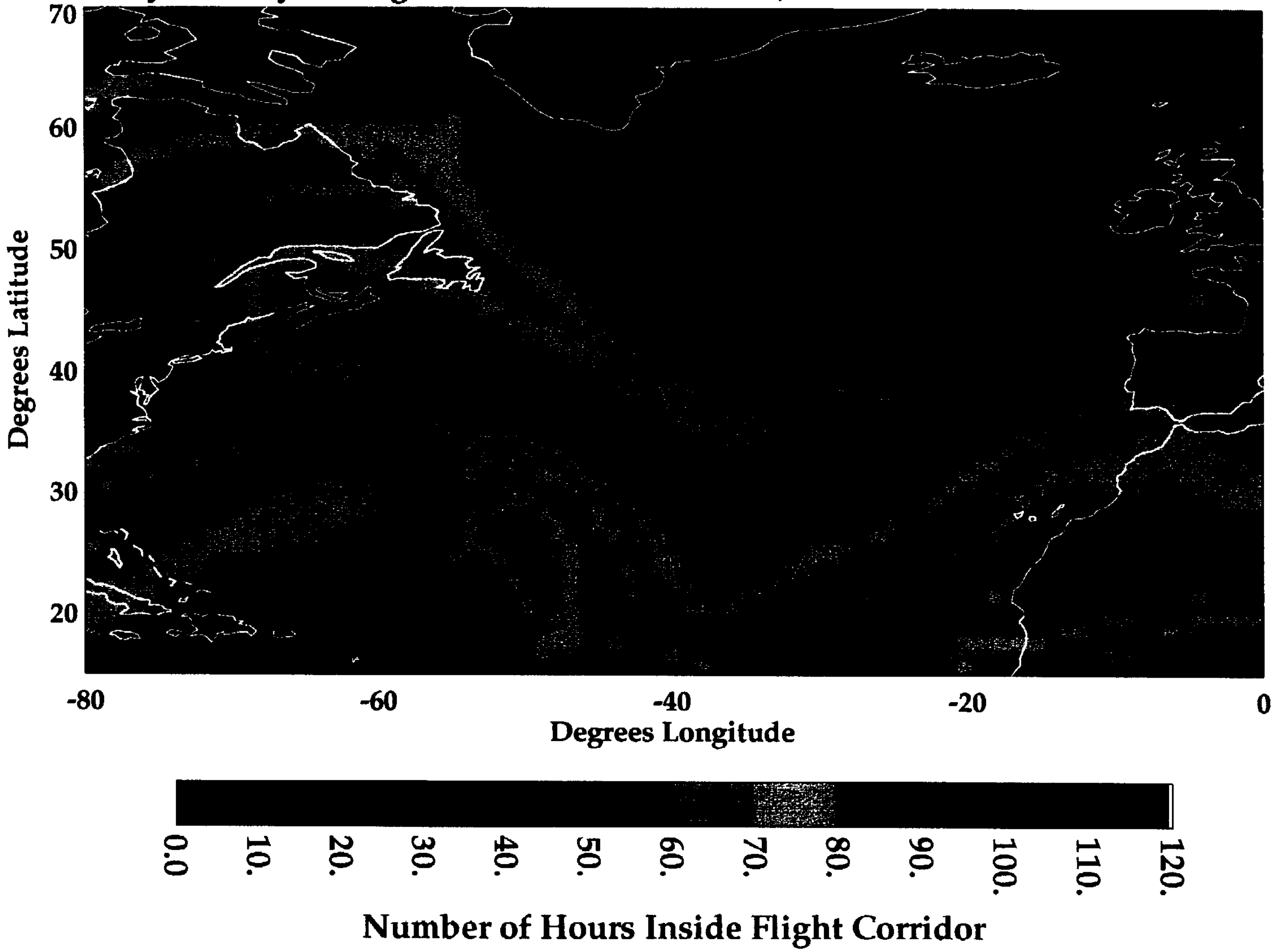

1997 10 19 00 +36
(1997 10 20 12)
aircraft_NOx Sigma 2
Chemistry prognoses from
Department of Geophysics
University of Bergen
> 0.040
0.036 – 0.040
0.032 – 0.036
0.028 – 0.032
0.024 – 0.028
0.019 – 0.024
0.015 – 0.019
0.011 – 0.015
0.007 – 0.011
0.003 – 0.007
< 0.003
40
35
30
25
20
15
10
5
15
20
25
30
35
40
45
50
55
60

PLATE 3b

5-Day History of Flight Corridor Encounters, 971020 12GMT Theta=350.000



NASA/GSFC/TKS/971018

PLATE 3C

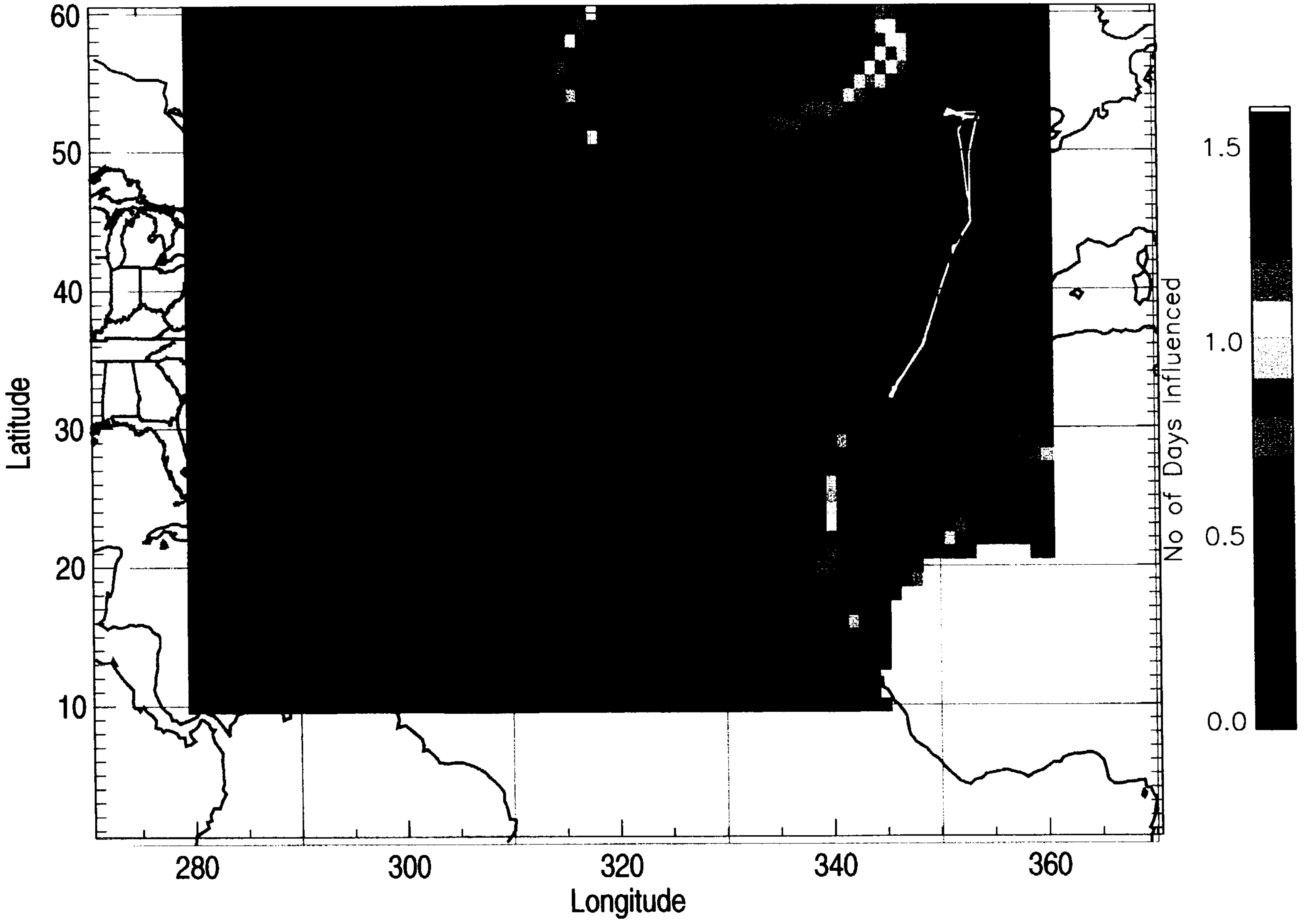

Con Inf over prvs 5 days at 9710201200 on 335K surf

PLATE 3