Part II

IERS Reports

INTERNATIONAL EARTH ROTATION SERVICE (IERS)
SERVICE INTERNATIONAL DE LA ROTATION TERRESTRE

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SEARCH'92/IGS'92 CAMPAIGN

COMPARISONS OF GPS, SLR, AND VLBI EARTH ORIENTATION DETERMINATIONS

(Final report)

Starting with IERS Bulletin B58, issued early December 1992 and covering October 1992, the GPS Earth Orientation Parameters will be introduced in the computation of the Central Bureau of IERS. Section 6 of Bulletin B will include statistics on the VLBI, LLR, GPS and SLR solutions received. The present Earth Orientation Bulletin is the last one issued in support to the IGS'92 campain.

GPS: TERRESTRIAL FRAME ORIENTATION FIXING

Various strategies are tested by the GPS Processing Centres for maintaining the terrestrial frame orientation. The choices concern the nominal orientation (ITRF90 or ITRF91), the site motion model used to transfer the coordinates at the reference epoch, the number of fiducial stations that are fixed, and the source from which the fixed coordinates are taken. We summarize in Table 1 our understanding of the terrestrial frame definitions according to the Centres and to the time periods.

Table 1
GPS SOLUTIONS: TERRESTRIAL FRAME ORIENTATION

Series (IERS label)	MJD from	MJD to	GPS weeks	Nominal refrnce	Source
EOP(CODE) 92 P 04	48792	48923	650-668	ITRF91	IERS (IGSMail 33)
EOP(CSR) 92 P 01	48794	48870	650-660		CSR+GSFC (IGSMail 62)
EOP(EMR) 92 P 01	48838	48904	655-665	ITRF91	IERS (IGSMAIL 90)
EOP(EMR) 92 P 02	48901	48911	655-666	ITRF91	IERS (IGSMAIL 90)
EOP(ESOC) 92 P 01	48794	48912	650-666	ITRF91	IERS (IGSMail 90)
EOP(GFZ) 92 P 01	48794	48821	650-653	ITRF90	SIO (01/91-05/92)
EOP(GFZ) 92 P 02	48822	48918	654-667	ITRF90	SIO (IGSMail 56)
EOP(JPL) 92 P 01	48794	48821	650-653	ITRF90	JPL (GIG'91+VLBI vel.)
EOP(JPL) 92 P 02	48820	48918	654-667	ITRF91	IERS (IGSMail 90)
EOP(SIO) 92 P 03	48780	48918	648-667	ITRF90	SIO (51 IGS'92 days)

VLBI, LLR, SLR, GPS EOP DETERMINATIONS: AGREEMENT WITH THE IERS SYSTEM

In this section, the VLBI, LLR, SLR, and GPS observations available over the time period of the IGS'92 Campaign and its continuation (MJD 48779-48923) are compared to the IERS series EOP(IERS) 90 C 04, which is a combination of the series of Table 2.

Table 2
IERS OPERATIONAL SERIES OF EOP

Techn.	Series	Time span	Time interv.	EOP determined
VLBI	EOP(NOAA) 92 R 01	24 h	3/4 d	x, y, UT1, dPsi, dEps
VLBI	EOP(NOAA) 92 R 02	1 h	1/2 d	UT1
VLBI	EOP(USNO) 92 R 03	24 h	7 d	x, y, UT1, dPsi, dEps
LLR	EOP(UTXMO) 92 M 02	1 h	0.1/30d	UT1
SLR	EOP(CSR) 91 L 01	72 h	3 d	x, y, "UT1"
SLR	EOP(DUT) 91 L 02	120 h	5 d	x, y, "UT1"

The GPS series are those listed in Table 1. They give the x,y coordinates of the pole, except CODE, which gives a series of UT1 that is tied at the beginning of the complete series to an a priori value,and the new EMR series, whith UT1 tied to an a priori value at the beginning of each week. The "UT1" determinations obtained by the SLR Analysis Centre at DUT is left free, whereas in the CSR SLR solution, it is tied to a VLBI solution for periods longer than about 60 days.

The GPS results are obtained from one-day observations of 16 to 18 satellites in a network of 11 to 29 stations: 14-19 for CODE, 14-20 for CSR, 17-18 for EMR, 11-18 for ESOC, 22-27 for JPL, and 17-29 for SIO.

Most of the centres treat independently the successive daily arcs, the exceptions being CODE (three-day overlapping arcs) and GFZ (two-day overlapping arcs). The centres estimate the EOP at 12h UT.

Table 3 gives the differences of the VLBI, SLR,and GPS series with EOP(IERS) 90 C 04 under the form of a constant bias, corrected for the predicted value of the systematic difference. In the case of the GPS results, which are referred directly to ITRF, the predicted bias and its uncertainty are derived from Table I-3, p.II-13 of the 1991 IERS Annual Report. It reflects the slight misalignment of the IERS EOP relative to the IERS terrestrial frame. In the case of the SLR and VLBI results, the expected values are derived from analyses of previous years results.

Table 3
SYSTEMATIC DIFFERENCES OF EOP RESULTS WITH IERS

Techn	Series	x (0.001")	y(0.001")	UT1(0.0001s)	Nmes
VLBI	EOP(NOAA) 92 R 01	-0.15 ± 0.08	-0.03 ± 0.09	0.00 ± 0.06	39
VLBI	EOP(NOAA) 92 R 02			0.11 ± 0.05	90
VLBI	EOP(USNO) 92 R 03	-0.43 ± 0.06	-0.12 ± 0.08	0.03 ± 0.06	27
LLR	EOP(UTXMO) 92 M 02			-0.91 ± 0.29	17
SLR	EOP(CSR) 91 L 01	0.09 ± 0.07	0.17 ± 0.05	0.10 ± 0.09	48
SLR	EOP(DUT) 91 L 02	0.98 ± 0.18	-0.84 ± 0.21		29
GPS	EOP(CODE) 92 P 04	-0.31 ± 0.36	-0.07 ± 0.45		122
GPS	EOP(CSR) 92 P 01	-0.18 ± 0.37	2.46 ± 0.48		69
GPS	EOP(EMR) 92 P 01	-0.44 ± 0.45	1.08 ± 0.46		44
GPS	EOP(EMR) 92 P 02	0.71 ± 0.39	-0.22 ± 0.46		8
GPS	EOP(ESOC) 92 P 01	1.01 ± 0.38	0.01 ± 0.48		112
GPS	EOP(GFZ) 92 P 01	-2.68 ± 0.43	-3.29 ± 0.56		27
GPS	EOP(GFZ) 92 P 02	+1.68 ± 0.36	1.92 ± 0.45		
68					
GPS	EOP(JPL) 92 P 01	-0.19 ± 0.38	1.51 ± 0.50		28
GPS	EOP(JPL) 92 P 02	0.09 ± 0.35	0.14 ± 0.45		79
				LOD: 0.16 ± 0.15	43
GPS	EOP(SIO) 92 P 03	0.35 ± 0.35	1.68 ± 0.44		137

GPS: FORMAL AND ESTIMATED UNCERTAINTIES

The correlation of high frequency variations in the GPS polar motion results was estimated on the basis of the residuals of each series of daily values relative to its own smoothing (frequency cutoff: 1 cycle/10 days). The common time intervals between two series cover 17 to 109 days. No significant correlation was found.

Using the days which are common to pairs of series without change of reference system, we estimate the true uncertainty of the daily EOP values by the Allan variance (or pair variance) based on the 15 series of differences two by two (see the 1991 IERS Annual Report, p.II-52). Table 4 shows the uncertainties thus estimated for every GPS series, together with the corresponding rms formal uncertainty provided by the Processing Centre.

Table 4
ESTIMATED AND FORMAL UNCERTAINTY OF DAILY GPS POLAR MOTION VALUES

Techn	Series	x (0.001")		y(0.001")		Nmes
		estim.	formal	estim.	formal	
GPS	EOP(CODE) 92 P 04	0.50	0.13	0.58	0.13	66
GPS	EOP(CSR) 92 P 01	0.59	0.20	0.69	0.20	75
GPS	EOP(EMR) 92 P 01	0.69	0.55	0.49	0.37	66
GPS	EOP(EMR) 92 P 02	0.48	0.23	0.39	0.20	8
GPS	EOP(ESOC) 92 P 01	1.02	0.39	1.14	0.42	82
GPS	EOP(GFZ) 92 P 01	1.11	0.86	1.11	0.89	26
GPS	EOP(GFZ) 92 P 02	0.75	0.47	0.40	0.52	66
GPS	EOP(JPL) 92 P 01	0.37	0.25	0.47	0.30	26
GPS	EOP(JPL) 92 P 02	0.10	0.21	0.42	0.23	66
GPS	EOP(SIO) 92 P 03	0.38	0.33	0.22	0.30	82

VLBI, LLR, SLR, GPS EOP DETERMINATIONS: DAY-TO-DAY AGREEMENT WITH IERS

The series of EOP obtained by VLBI, LLR, SLR and GPS already considered in Table 3 are considered now under the form of the weighted rms residual to EOP(IERS) 90 C 04, after the biases of Table 2 are taken out. The statistics are listed in Table 5.

Table 5
WEIGHTED RMS DIFFERENCES OF EOP RESULTS WITH EOP(IERS) 90 C 04
The biases of Table 3 are taken out.

Techn	Series	x (0.001")	y(0.001")	UT1(0.0001s)	Nmes
VLBI	EOP(NOAA) 92 R 01	0.47	0.58	0.36	39
VLBI	EOP(NOAA) 92 R 02			0.48	90
VLBI	EOP(USNO) 92 R 03	0.30	0.42	0.29	27
LLR	EOP(UTXMO) 92 M 02			1.18	17
SLR	EOP(CSR) 91 L 01	0.47	0.37	0.62 (1)	48
SLR	EOP(DUT) 91 L 02	0.90	1.08	3.41 (2)	29
GPS	EOP(CODE) 92 P 04	0.83	0.89	0.89 (3)	132
GPS	EOP(CSR) 92 P 01	0.90	1.57	2.73	69
GPS	EOP(EMR) 92 P 01	1.45	0.80		44
GPS	EOP(EMR) 92 P 02	0.49	0.39		8
GPS	EOP(ESOC) 92 P 01	1.29	1.73		112
GPS	EOP(GFZ) 92 P 01	1.35	1.83		27
GPS	EOP(GFZ) 92 P 01	1.04	0.72		76
GPS	EOP(JPL) 92 P 01	0.72	1.31		28
GPS	EOP(JPL) 92 P 02	0.42	0.48		78
				LOD : 0.99	43
GPS	EOP(SIO) 92 P 03	0.67	0.62		137

Notes : 1 - CSR - Referred to VLBI in the long term (p > 60 d).
2 - DUT - With a drift of +0.027 ms/d and a quadratic term taken out.
3 - CODE - With a drift of +0.045 ms/d, a quadratic term and a 92d periodic term taken out.

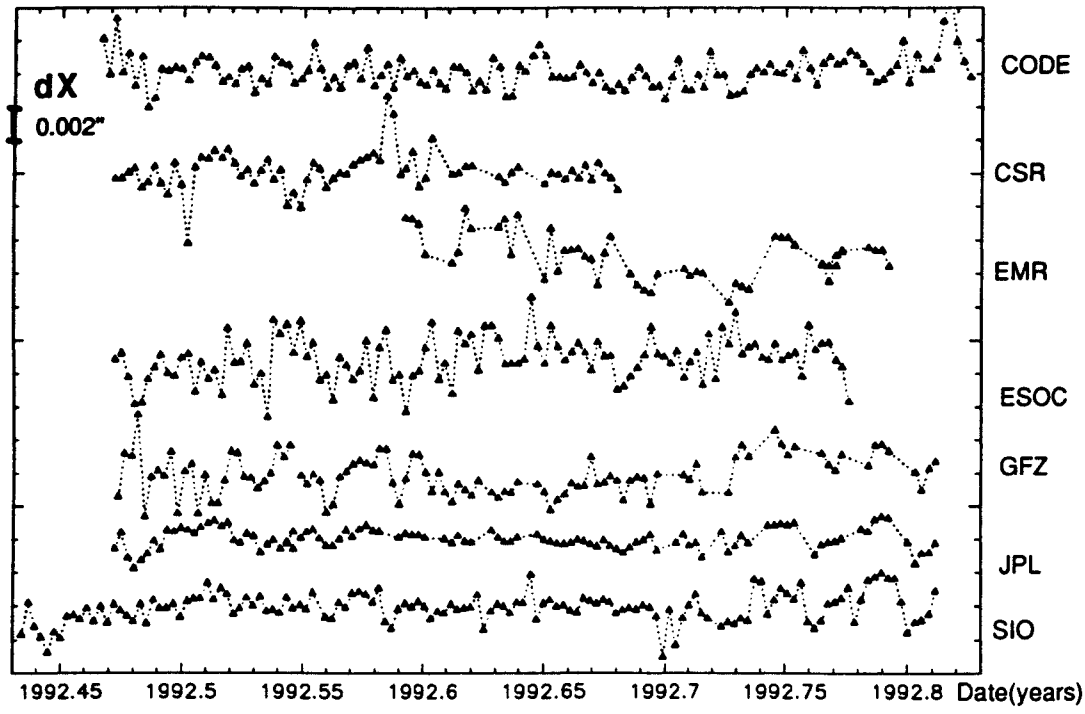

Fig. 1 Differences of the GPS series of the x coordinate of the pole with EOP(IERS) 90 C 04

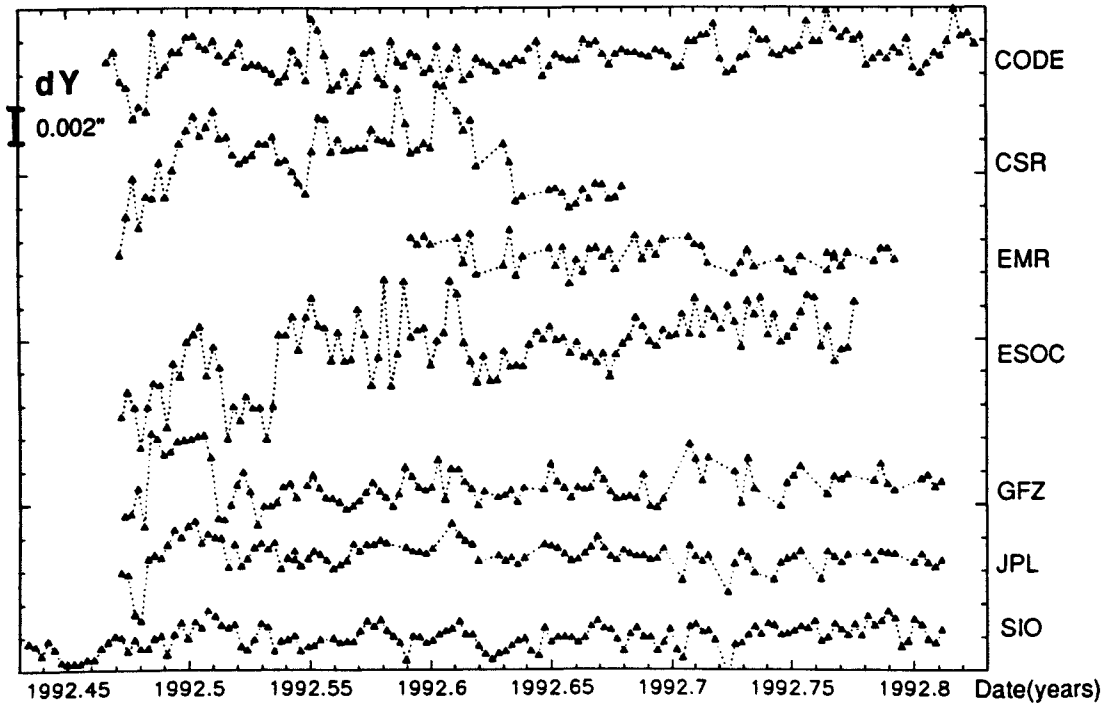

Fig. 2 Differences of the GPS series of the y coordinate of the pole with EOP(IERS) 90 C 04

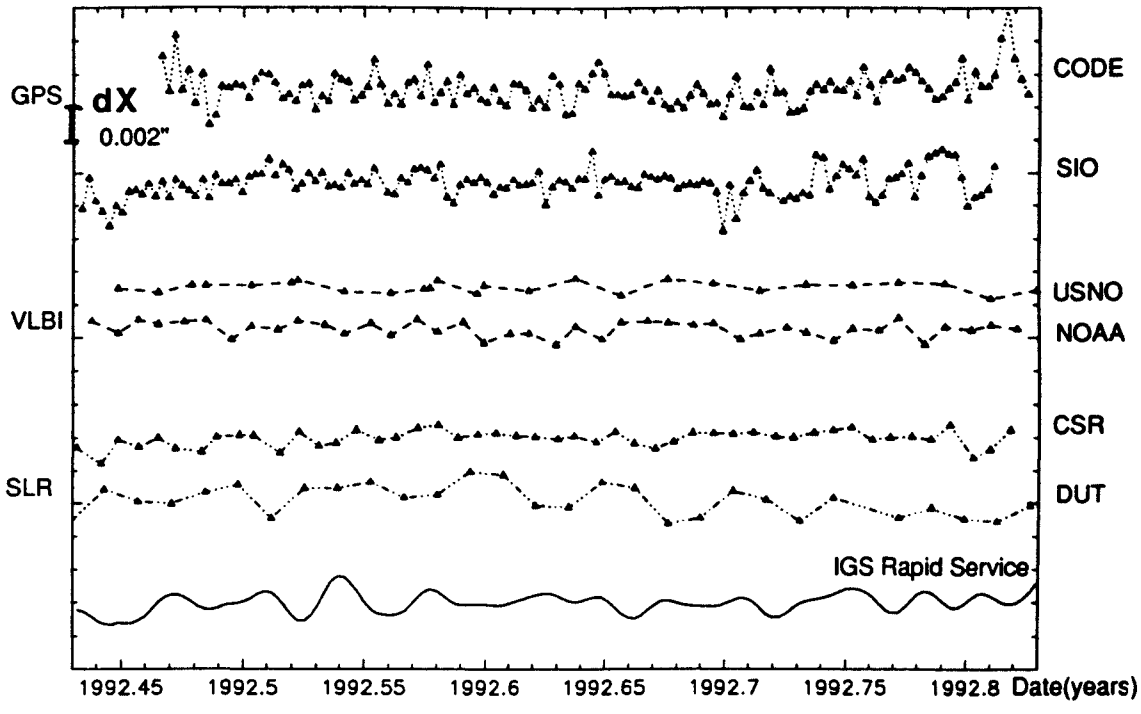

Fig. 3 Differences of GPS, SLR, VLBI, and Rapid Service series of the x coordinate of the pole with EOP(IERS) 90 C 04

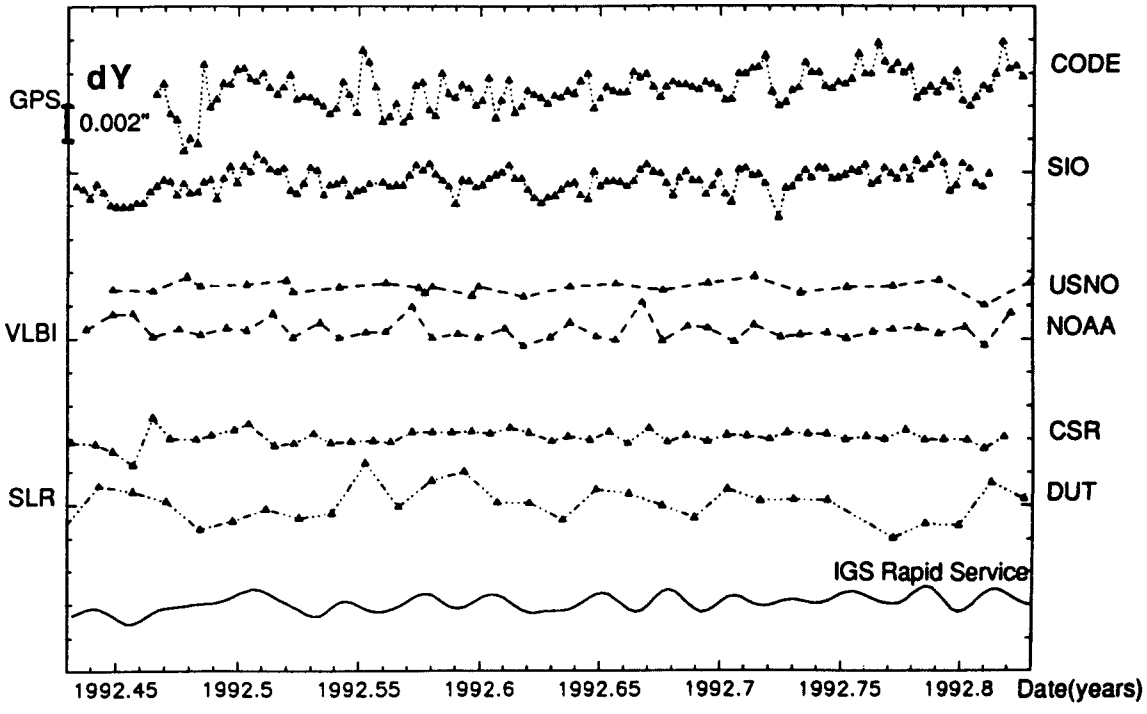

Fig. 4 Differences of GPS, SLR, VLBI, and Rapid Service series of the y coordinate of the pole with EOP(IERS) 90 C 04

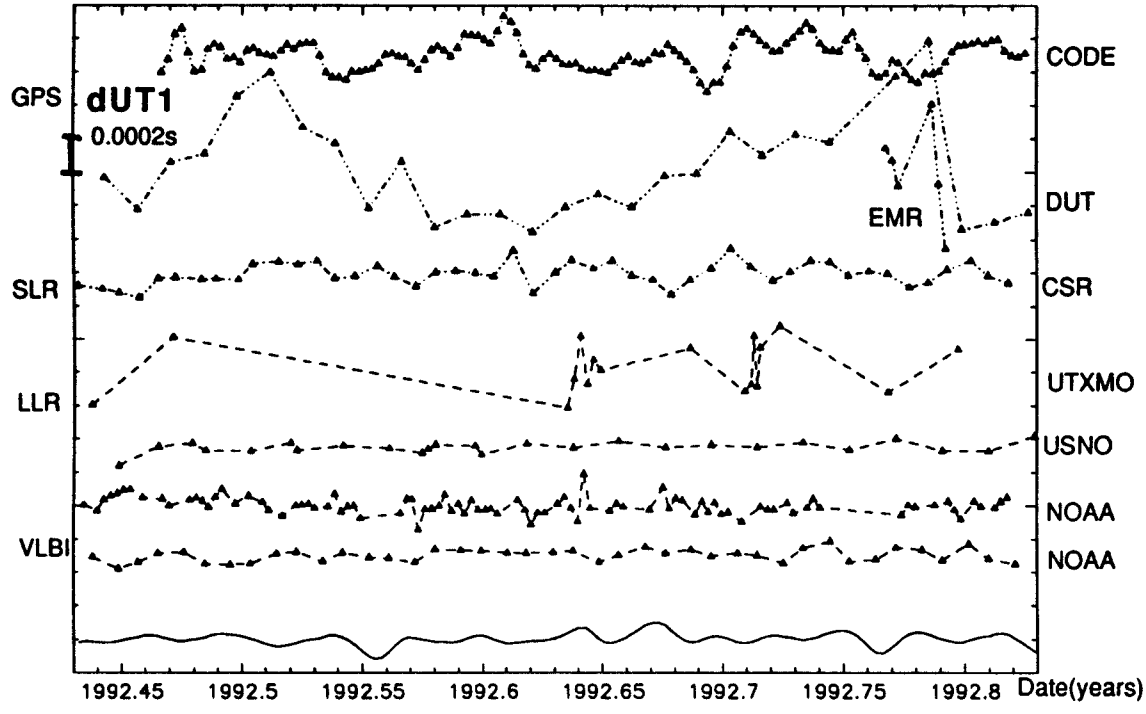

Fig. 5 Differences of GPS, SLR, VLBI, and Rapid Service series of Universal time with EOP(IERS) 90 C 04

Notes : 1 - CSR - Referred to VLBI in the long term (p > 60 d).
2 - DUT - With a drift of +0.027 ms/d and a quadratic term taken out.
3 - CODE - With a drift of +0.045 ms/d, a quadratic term and a 92d periodic term taken out.

THE USE OF GPS EARTH ORIENTATION DATA BY THE INTERNATIONAL EARTH ROTATION SERVICE SUB-BUREAU FOR RAPID SERVICE AND PREDICTIONS

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The International GPS Service provides polar motion data which have become an important contribution to the operation of the International Earth Rotation Service (IERS) Sub-bureau for Rapid Service and Predictions. Comparison with other techniques shows that these data provide estimates of the position of the rotational pole with an accuracy of approximately ± 0.5 milliseconds of arc. This accuracy along with the fact that the daily data are available soon after observation could make this source of data a valuable addition to the contributors to the IERS.

INTRODUCTION

Analyses of the orbits of the satellites of the Global Positioning System (GPS) by participants in the International GPS Service (IGS) (Mueller and Beutler, 1992) have provided daily observations of high-accuracy polar motion described by the pole coordinates, x along the Greenwich meridian, and y along the meridian of ninety degrees west. These data are used routinely by the IERS Sub-bureau for Rapid Service and Prediction in its normal operations. The GPS data have also been analyzed by some centers to produce estimates of UT1-UTC. Because of unresolved apparent systematic error in these data, however, they are not being used operationally by the Sub-bureau. Also, a longer series of GPS Earth orientation information is required to assess the value of the data in maintaining a reference system over a long period of time. The purpose of this paper is to provide an assessment of these observations and show how this information is used currently.

The National Earth Orientation Service (NEOS) serves as the IERS Sub-bureau for Rapid Service and Predictions. It is comprised of the U. S. Naval Observatory and the National Ocean Services of the National Oceanic and Atmospheric Administration of the United States. Each week NEOS publishes, in IERS Bulletin A, information for approximately 350 users regarding the orientation of the Earth with respect to a celestial reference frame. These data are near real-time estimates of the orientation of the Earth as well as their predictions. This information is obtained from contributors who provide data obtained from very long baseline radio interferometry, laser ranging to satellites and the Moon, and now, from the analyses of GPS orbits.

SOURCES OF DATA

Daily estimates of pole positions have been provided by contributors to the IGS. These contributors include the Department of Energy, Mines, and Resources (EMR), the European Space Agency (ESOC), the GeoForschungsZentrum (GFZ), Jet Propulsion Laboratory (JPL), Scripps Institute of Oceanography, the University of Berne, and the University of Texas Center for Space Research. Estimates of UT1-UTC are contributed by EMR and the University of Berne.

ANALYSIS OF GPS DATA

The time series contributed by each of the institutions mentioned above were analyzed by comparing them with the National Earth Orientation Service (NEOS) combination series produced for the International Earth Rotation Service (IERS) Bulletin A. The data used to produce this series are derived from Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR). Figures 1 and 2 show plots of recent differences in polar motion after the removal of biases. Table 1 shows the statistical analysis of the polar motion data.

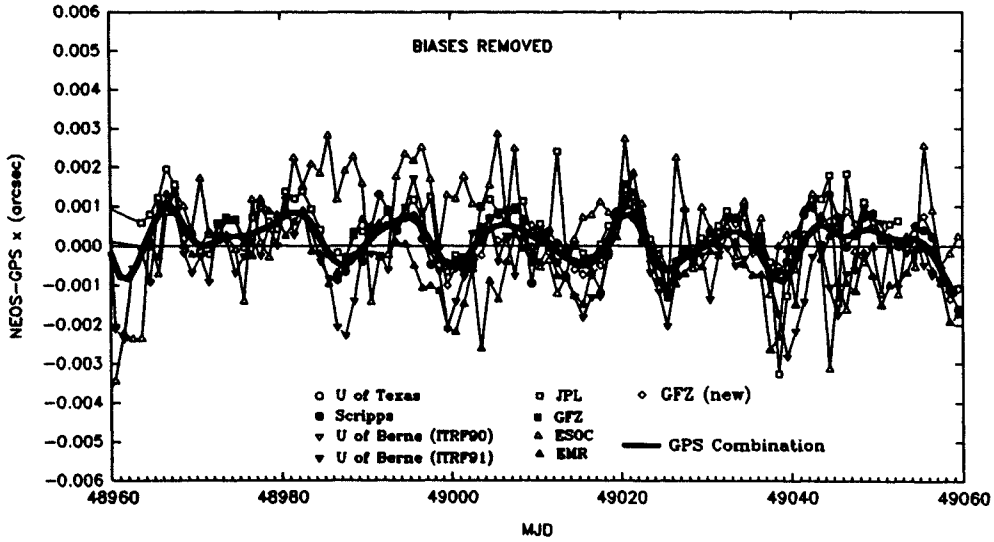

Figure 1. GPS data in x.

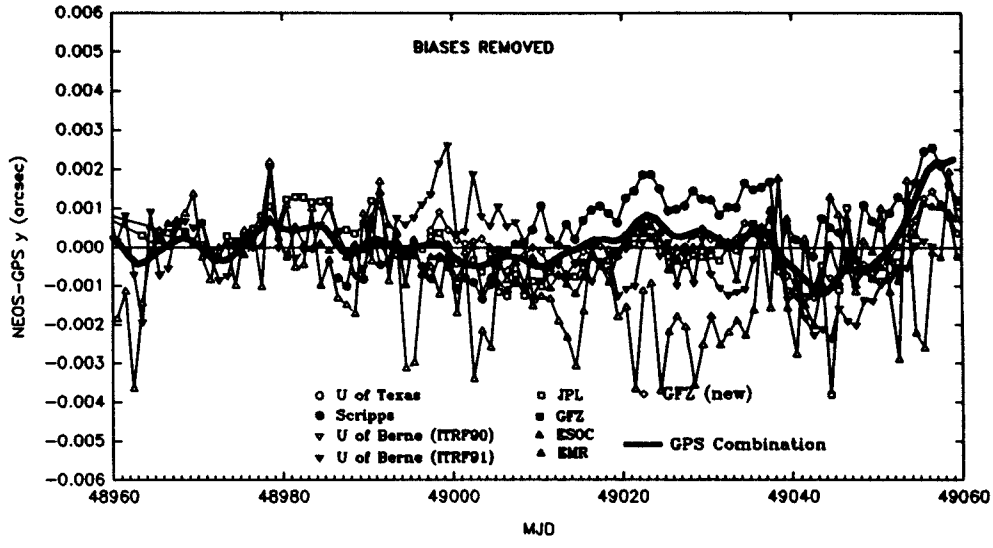

Figure 2. GPS data in y.

Table 1. Comparison of GPS data with NEOS. Units are milliseconds of arc.

Contributor	Data Span (MJD)	Points	Mean (NEOS-GPS) x	Mean (NEOS-GPS) y	Standard Deviation x	Standard Deviation y
U. of Texas	48794.5-48880.5	76	-1.89	-3.11	0.82	0.63
Scripps	48780.5-49052.5	236	-1.56	-0.81	0.65	0.67
U. of Berne (ITRF90)	48792.5-48799.5	8	-0.89	1.21	1.52	1.88
U. of Berne (ITRF91)	48800.5-49056.5	257	-0.51	-0.19	0.95	0.89
JPL	48794.5-49045.5	220	-0.79	0.01	0.82	0.74
GFZ	48795.0-48925.5	107	-2.33	-1.99	1.13	1.12
ESOC	48794.5-49052.5	259	-1.17	-0.89	1.42	1.85
EMR	48838.5-49059.5	176	-1.06	0.32	1.07	0.74
GFZ (New Series)	48997.0-49059.5	63	1.89	-1.48	0.57	0.58

USE OF GPS DATA IN IERS BULLETIN A

The NEOS now makes use of GPS data contributed to the IERS in its combination series. This is done by smoothing the contributed data separately using algorithms similar to that used in the procedure to combine the VLBI, SLR and LLR data now (McCarthy and

Luzum, 1991). The smoothed fit is shown in Figures 1 and 2 as a thick solid line. Statistical weights are assigned to each of the contributors based on their past agreement with the NEOS combination series. Figures 3 and 4 show the agreement between the smoothed GPS estimates and those derived using data from other techniques for recent times.

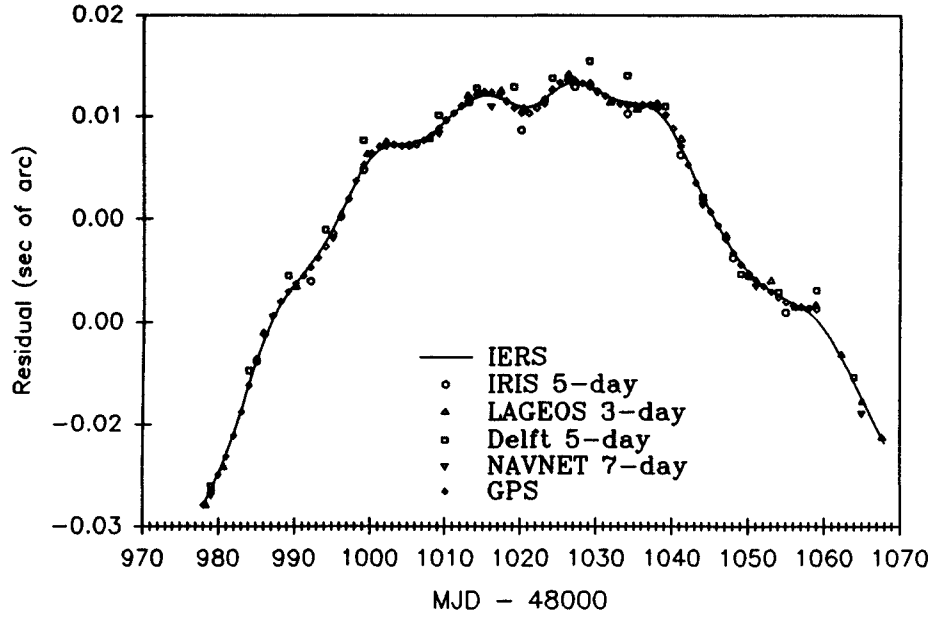

Figure 3. x minus a linear fit.

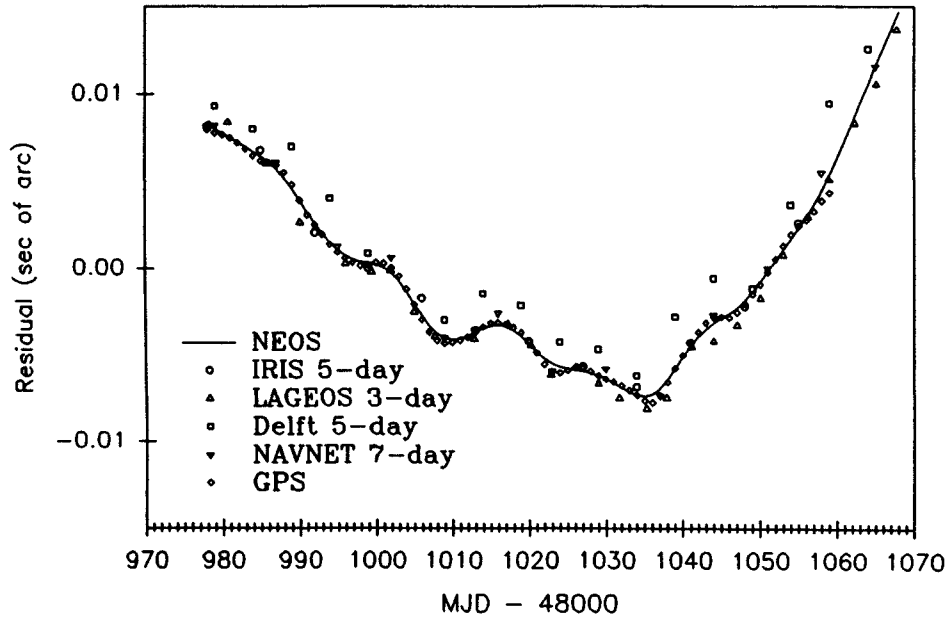

Figure 4. y minus a linear fit.

ACCURACY

Comparison with the other techniques shows that the combined GPS series has an accuracy of ± 0.55 msec of arc in x and ± 0.48 msec of arc in y. Figures 1 and 2 show that serious systematic differences between the contributors remain which must be resolved to obtain further improvement.

CONTRIBUTION TO RAPID SERVICE AND PREDICTIONS

The contribution to the rapid service estimates of polar motion and prediction are shown graphically in Figure 5. The term "contribution" is estimated by taking into account the frequency with which the data are reported, the adopted *a priori* accuracy of each contributor, and the time delay between the epoch of the last available data point and the date of the weekly publication. It is a measure of the overall weight of the data in the weekly solution.

The contribution of the GPS data to the long-term maintenance of the reference frame remains unclear. A longer series of data is required to assess the value of the information in preserving a reference system over an extended period.

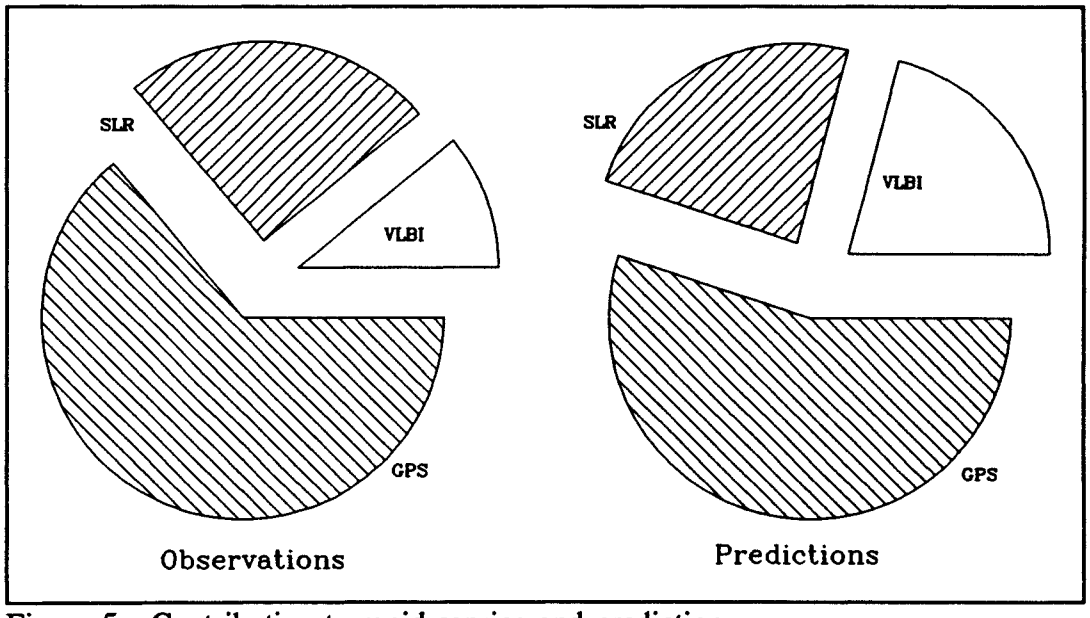

Figure 5. Contribution to rapid service and prediction.

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Mueller, I. I., and Beutler, G. (1992). The International GPS Service for Geodynamics - Development and Current Structure, *Proceedings of the Sixth International Geodetic Symposium on Satellite Positioning*.

ACTIVITIES OF THE SUB-BUREAU FOR ATMOSPHERIC ANGULAR MOMENTUM IN SUPPORT OF SEARCH'92

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ABSTRACT. This article describes the role that the Sub-bureau for Atmospheric Angular Momentum (SBAAM) of the International Earth Rotation Service (IERS) played during the special SEARCH'92 (Study of Earth-Atmosphere Rapid Changes) campaign. During this period, atmospheric angular momentum values and related parameters from all four participating meteorological centers were received and archived by the SBAAM. Also, values of components of the torques linking the atmosphere and its underlying surface were received from one of the centers. These data sets are most useful for studying the high-frequency dynamic interactions which were the focus of the SEARCH'92 campaign.

1. Introduction

During portions of the SEARCH'92 campaign, held during the three-month period 21 June-22 September 1992, the Sub-bureau for Atmospheric Angular Momentum received very high frequency atmospheric angular momentum data, at 6-hourly resolution, from three meteorological centers, the U.S. National Meteorological Center (NMC), the Japan Meteorological Agency (JMA), and the European Centre for Medium Range Weather Forecasts (ECMWF). Data from the fourth participating center, the United Kingdom Meteorological Office, was received at 12-hourly resolution. The atmospheric angular momentum parameters, which are related to Earth rotation, were made available to a network of international scientists, as well as to the IERS. In addition, personnel at the U.S. NMC have been producing values of the components of torques between the atmosphere and solid Earth, which are derived from the weather forecasting and analysis models.

2. SBAAM Parameters

Effective atmospheric angular momentum (EAAM) functions were developed by Barnes *et al.* (1983), who related atmospheric motions and mass distribution to Earth rotation and polar motion, and their use in an operational setting has been discussed by Salstein et al. (1993). The first two functions, χ_1 and χ_2, are the equatorial components and are associated with the excitation of polar motion. The axial component, χ_3, is involved with changes in the length of day. The functions can be

further partitioned into contributions by wind and pressure. The calculation of wind contributions involves the computation of integrals over the depth of the atmosphere, which varies in the global models. Therefore, wind contributions to 100 hPa, as well as to the top of the model, were specified so that values from the various centers could more accurately be compared. Changes in the mass distribution, and hence the moment of inertia, of the atmosphere, are closely related to its two-dimensional surface pressure field. The pressure-related components from the centers can be compared without regard to the vertical construction of the model. A key issue is the extent to which an equilibrium response of the ocean modifies the changes in the pressure distribution felt by the solid Earth. At certain time scales, this inverted barometer (IB) response acts to reduce the equivalent angular momentum fluctuations of the atmosphere. Because the IB exists to at least a certain extent, calculations with a global IB correction are performed in parallel to the regular pressure terms. These excitation parameters are given at very high resolution for much of the SEARCH'92 period.

Other meteorological parameters are included in the Sub-Bureau files. Zonal mean zonal wind, from which the χ_3 term can be calculated, and zonal mean temperatures, whose gradients are related to overall zonal winds, are SBAAM analysis fields. Routine specification of the mass distribution of the atmosphere, expressed in low-order spherical harmonic expansions, is important in the study of various problems in geodynamics and geodesy, including the effects of mass redistribution on satellite orbits. These coefficients are also SBAAM fields.

The analysis file at high resolution is calculated either six-hourly (00, 06, 12, and 18 UTC) or twelve hourly (00 hr and 12 hr UTC), as specified, and consists of the following set of parameters:

1) hemisphere values of χ_1, χ_2, and χ_3, for wind to top of model, wind to 100 hPa, and pressure, and pressure + inverted barometer (6 hourly)

2) zonal mean zonal winds (m/s) at 5 degree latitude interals at 12 mandatory pressure levels (1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70 and 50 hPa) (12 hourly)

3) zonal mean temperatures (K) at the same grid as the zonal mean zonal winds (12 hourly)

4) mean surface pressure (hPa) over the globe (6 hourly) ; and

5) low-order coefficients of surface pressure, including spherical harmonics in full triangular truncation to degree 4 and zonal harmonics to degree 20 (6 hourly).

In addition, forecasts of the EAAM functions are part of the normal SBAAM products. These are made at 12-hour lead times out to 10 days or to the limit of the model if less than 10 days. The 12-hour interval was selected so that models with different start times could be validated at the same time. The EAAM functions χ_1, χ_2, and χ_3, are globally integrated for wind to top of model, for wind to 100 hPa, for pressure, and for pressure + inverted barometer.

3. Results for the SEARCH'92 Period

Figs. 1a-1c show the excitation quantities for the three-month SEARCH'92 period from NMC, ECMWF, and JMA, the centers which have provided very high resolution analysis data. Some points to note are as follows. The winds terms are to the top level of the center, noted in the figures, and so vary from the different centers. Values are given at the highest temporal resolution possible.

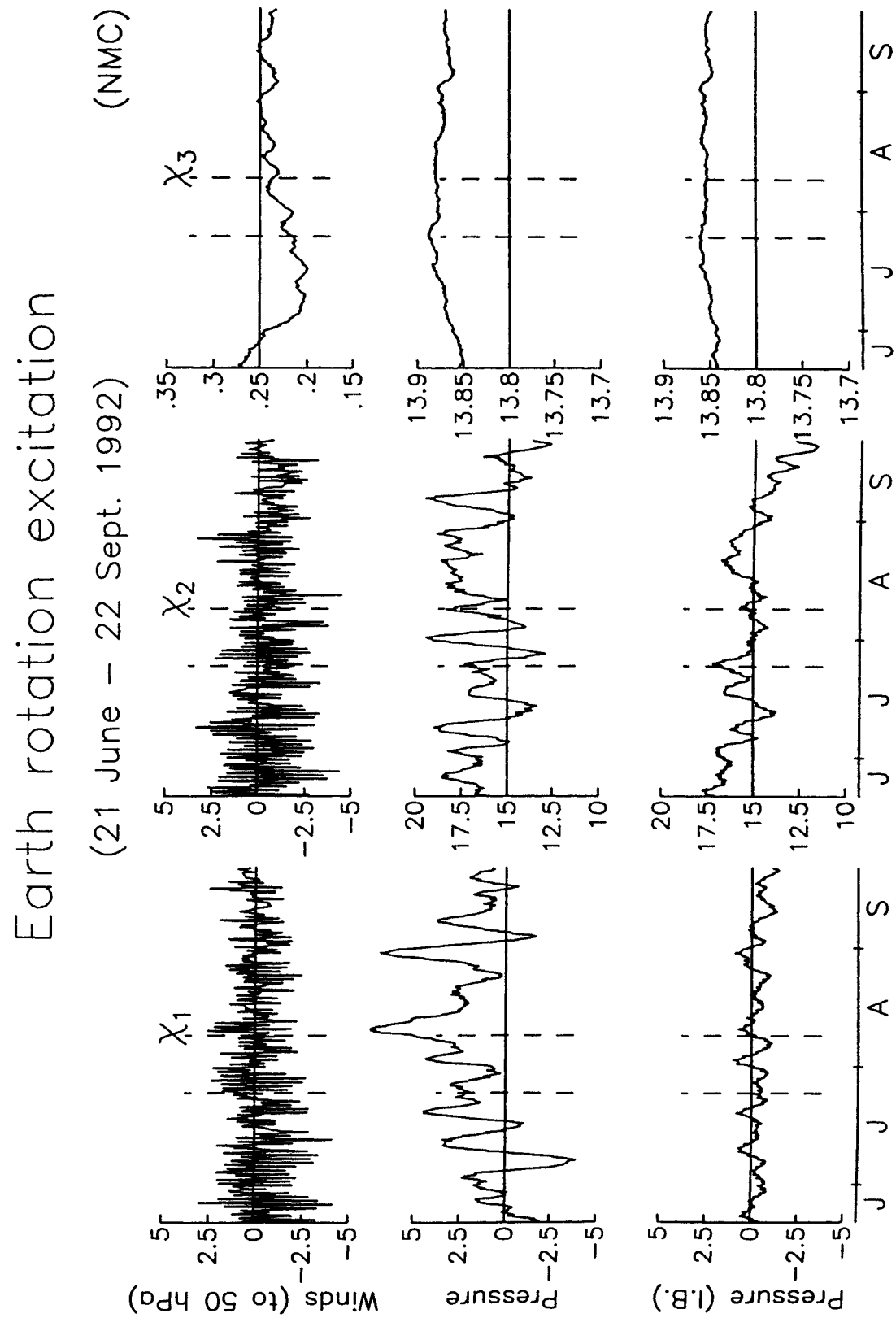

Figure 1a. Values of the global effective atmospheric angular momentum functions χ_1, χ_2, and χ_3 for wind, pressure, and pressure (inverted barometer) from the NMC analysis system for the whole period of SEARCH'92 (21 June-22 September 1992), given four times per day, as available. Units are non-dimensional multiplied by 10^{-7}. Vertical dashed lines denote the intensive period of the campaign.

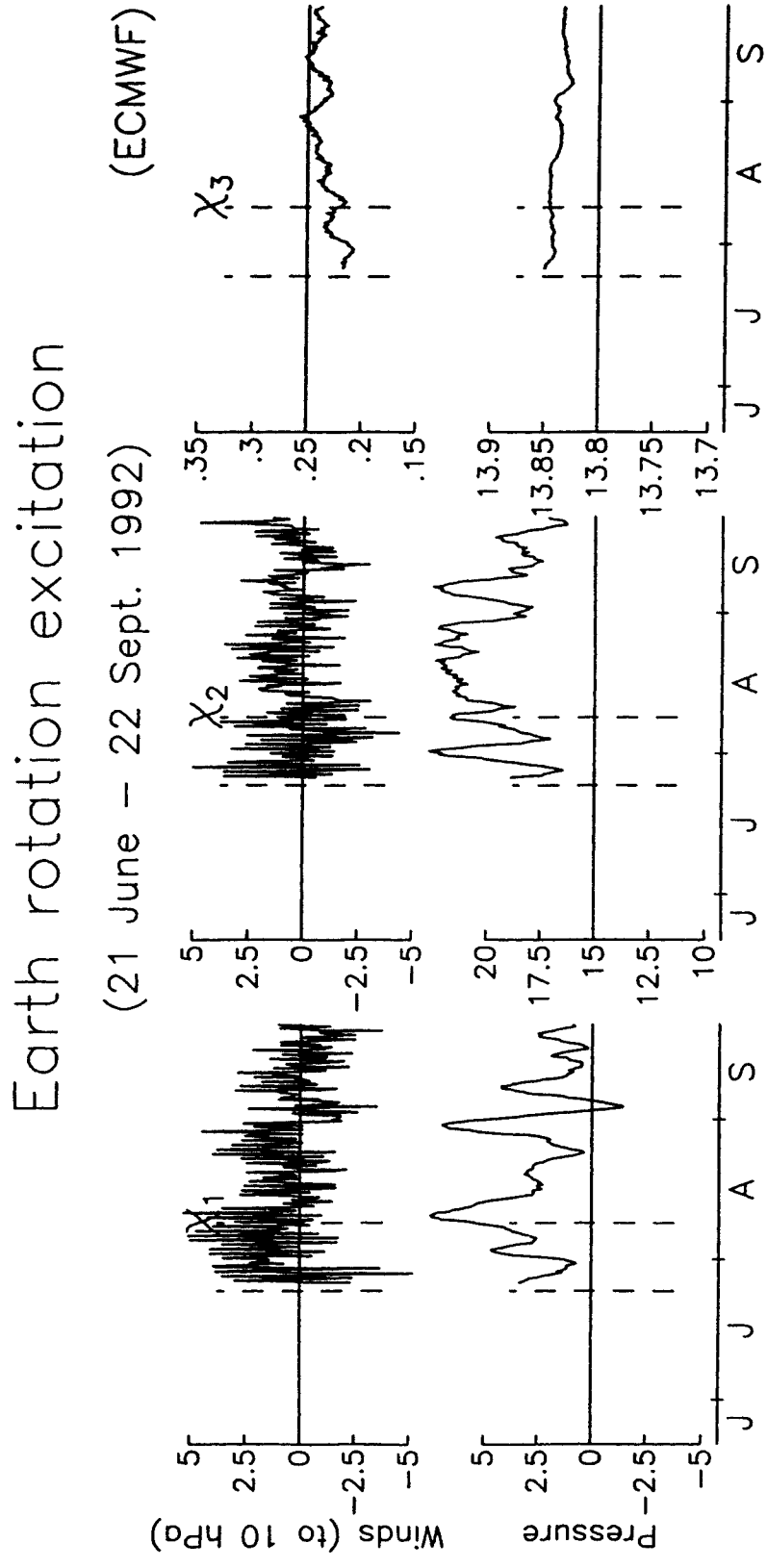

Figure 1b. Same as Figure 1a, but for the ECMWF system.

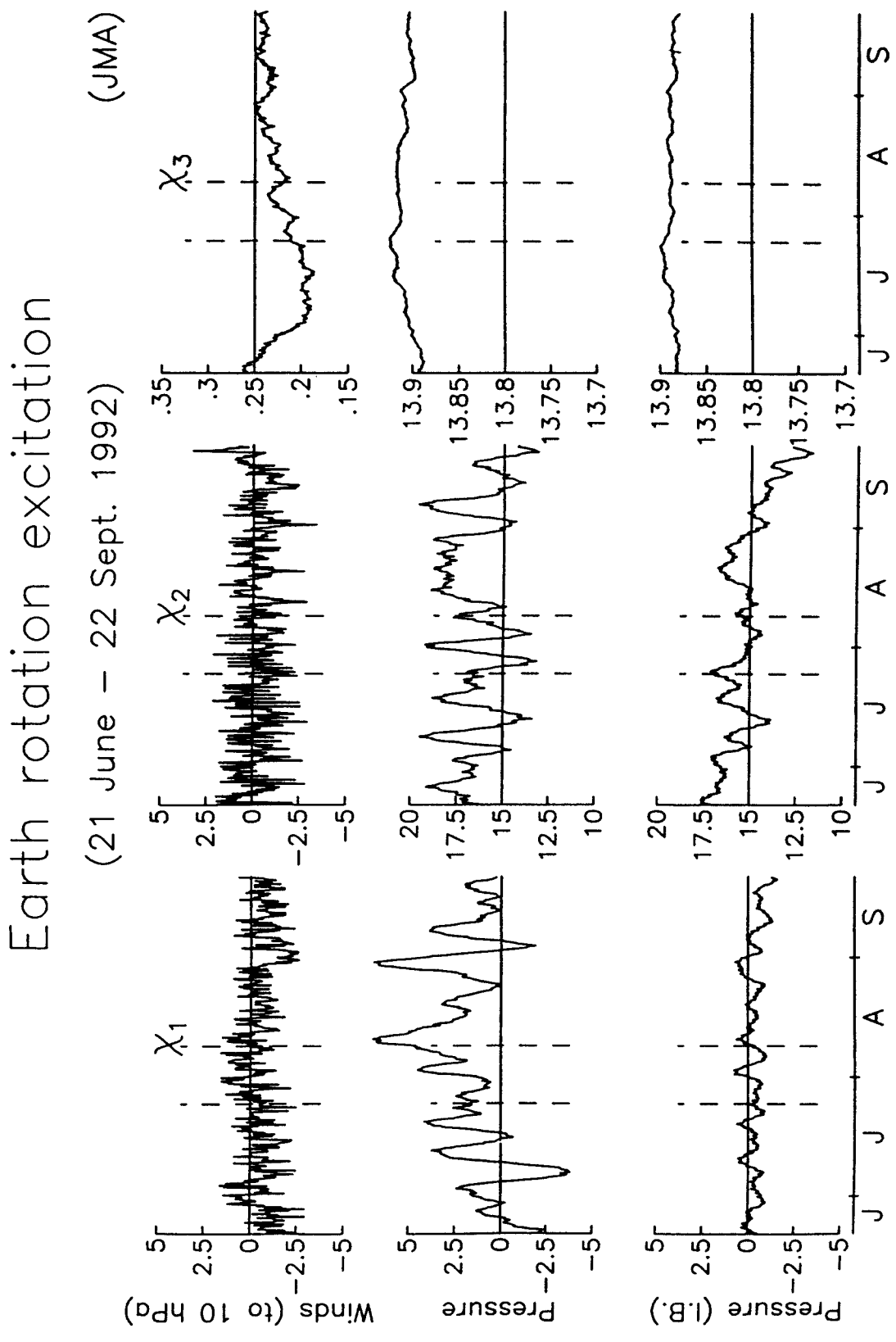

Figure 1c. Same as Figure 1a, but for the JMA system.

In order to best observe the diurnal variations, data from the two week intensive period, 25 July-8 August are given in Fig. 2 for the three centers. The sub-diurnal variability present in the χ_1 and χ_2-wind terms are likely due to the tidal response of the atmosphere to thermal forcing; such types of variations have been discussed by Hsu and Hoskins (1989). Six-hourly data are necessary to resolve these parameters, and so the SEARCH'92 period was the first in which we examined such fluctuations in both these equatorial wind parameters. The amplitude of the tidal response appears greater in the ECMWF fields than in the NMC fields, probably due to the higher level over which the former center calculated its wind values. Values for 06 and 18 UTC from the JMA, in particular, provided a weaker amplitude of this tidal signature during these synoptic times than the other centers. These hours are ones when fewer meteorological observations are taken.

The different mean values of the pressure-related excitation terms are likely due to the differences in topography of the three models. Each of the models uses its own representation of the surface topography, which relates to the overall surface pressure, and mass, of the atmosphere, and hence the pressure-based excitation (χ-p) terms.

Values of the low-order coefficients of a spherical harmonic representation of the surface pressure, truncated to degree 4, based on the NMC system, are given in Figure 3a and b for the intensive period of SEARCH'92. The two portions of the figure contain the real and imaginary coefficients, respectively.

4. Earth-Atmosphere Torques during the SEARCH'92 Period

The atmosphere exchanges its momentum with the underlying surface by means of two separate processes involving forces applied at the atmosphere's underlying boundary whose moment arm is the distance from the Earth's surface to its axis. These two torques arise from (i) a normal pressure gradient force against the Earth's topography, usually called a mountain torque, and (ii) a tangential stress against the underlying surface, either ocean or solid land, which is termed a friction torque. Global values of these two torques have been computed from the U.S. National Meteorological Center's analysis-forecast system every 6 hours for the SEARCH'92 period and kindly supplied by G.H. White. The procedure used to calculate these values is described by White (1991).

In Fig. 4 the global values of the 6-hourly mountain and friction torques, as well as their diurnal average is given. Also shown is the sum of the two terms on a daily averaged basis and changes in the axial angular momentum of the atmosphere. This daily agreement is good, but not perfect; whereas momentum is derived from a combination of observations and values forecast by the meteorological prediction model in data sparse areas, the torque terms are related also to physical parameterizations and other approximations in the forecast portion of the NMC model. On a 6-hourly basis, however, the two terms agree less, raising the difficulty of defining the momentum variation at these extremely short time scales. One item to note is that friction torque tends to be less variable that mountain torque, over these short periods.

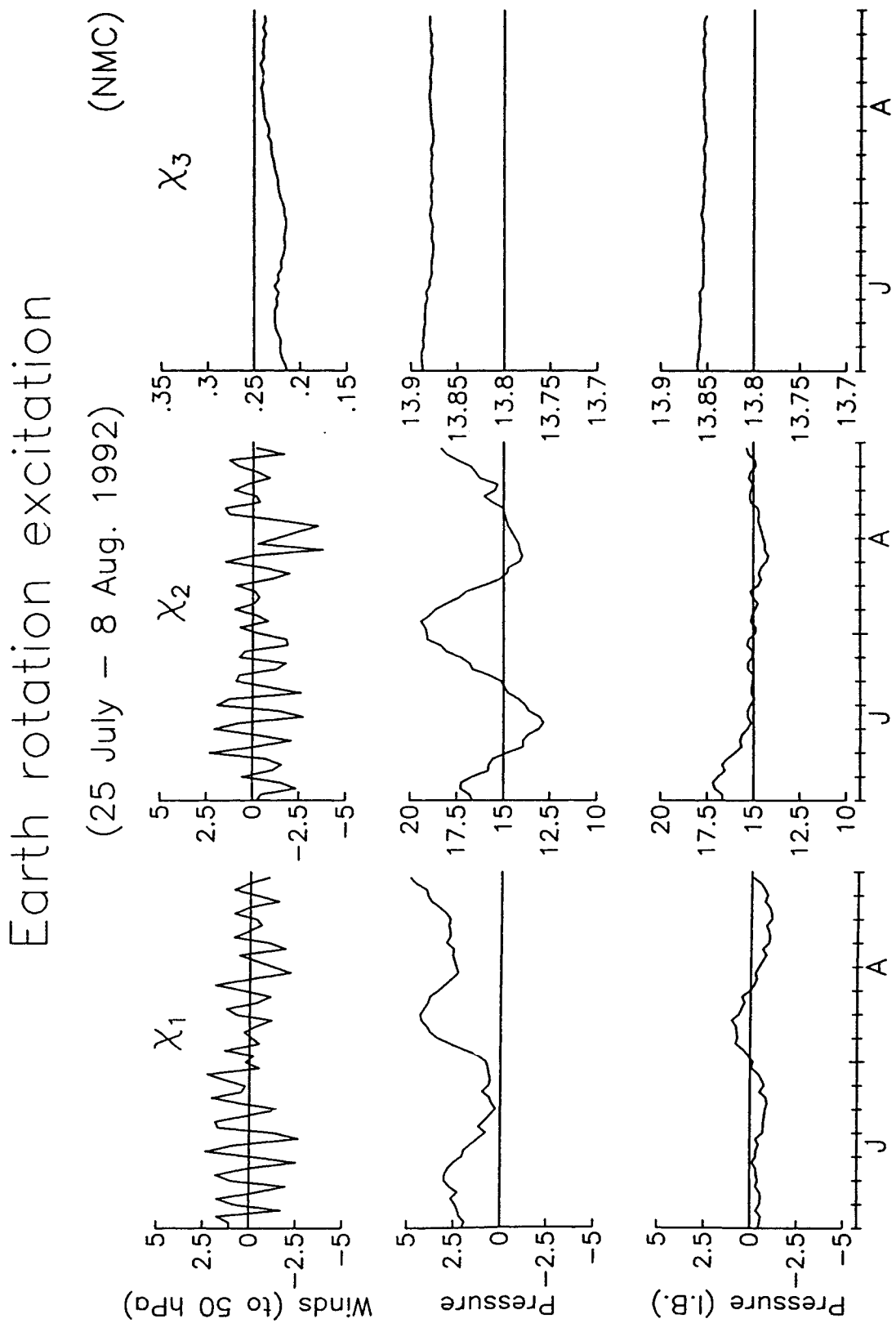

Figure 2a. Same as Figure 1a, but for the intensive period of SEARCH'92 (25 July–8 August 1992).

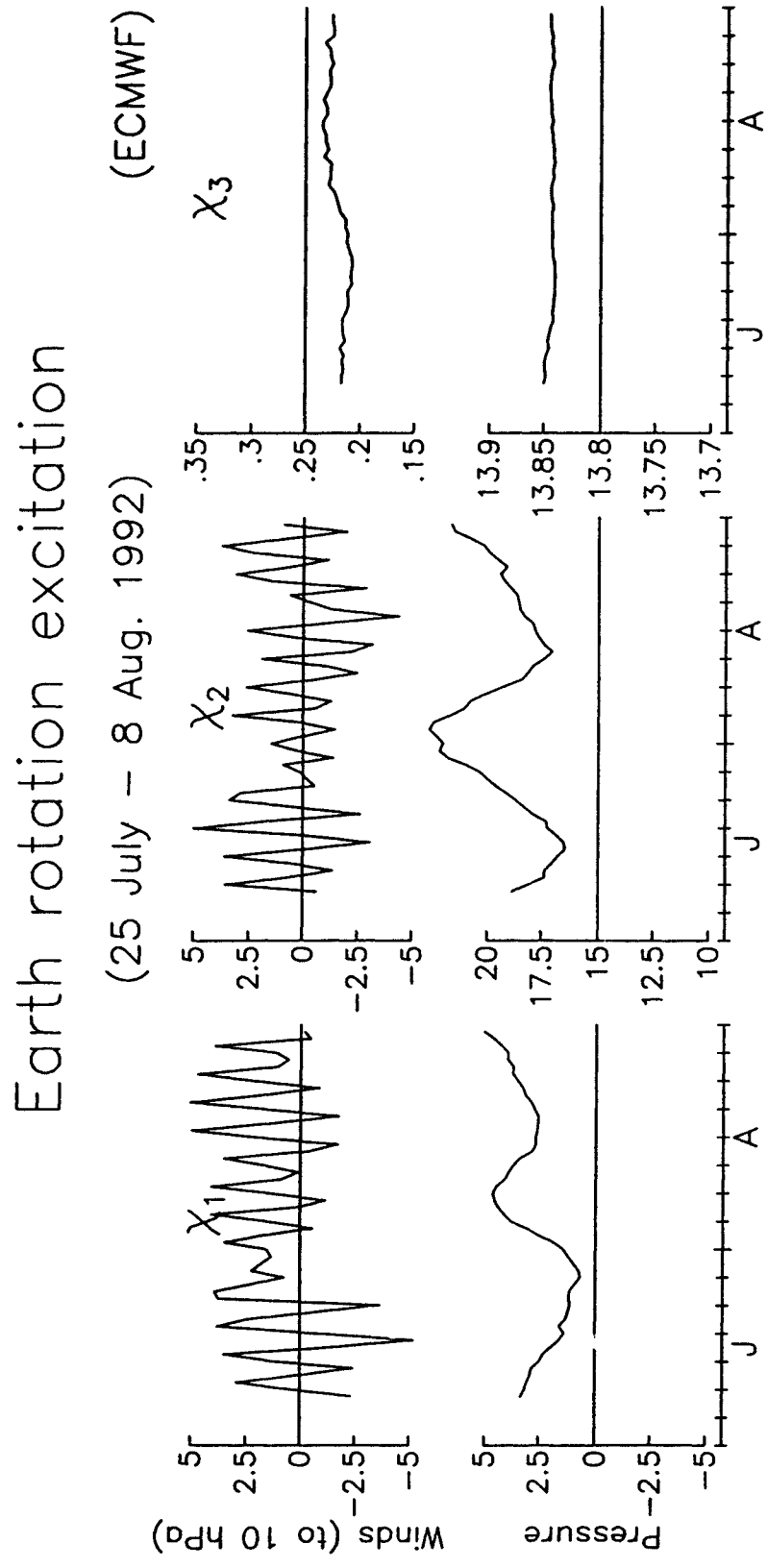

Figure 2b. Same as Figure 2a, but for the ECMWF system.

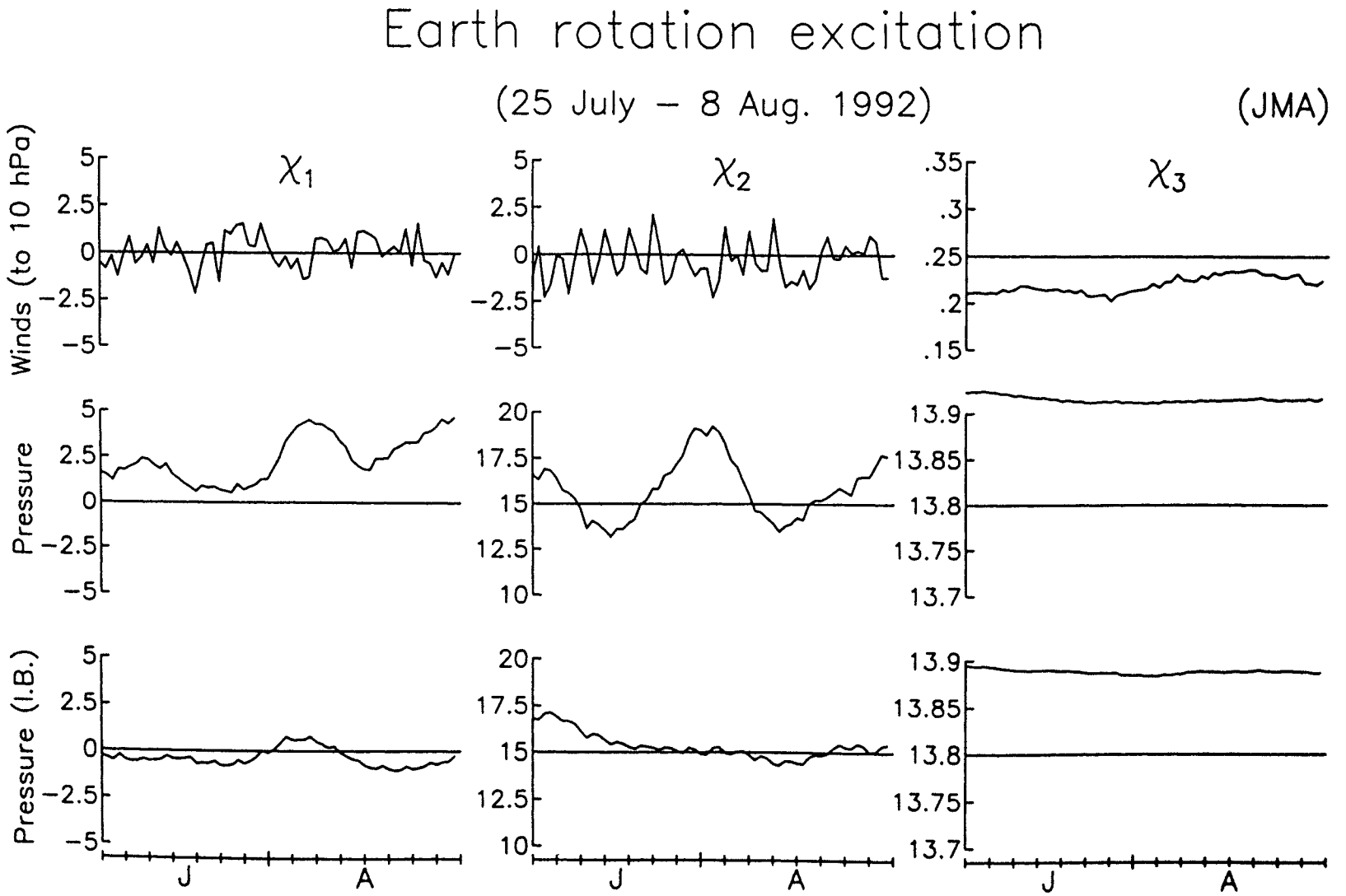

Figure 2c. Same as Figure 2a, but for the JMA system.

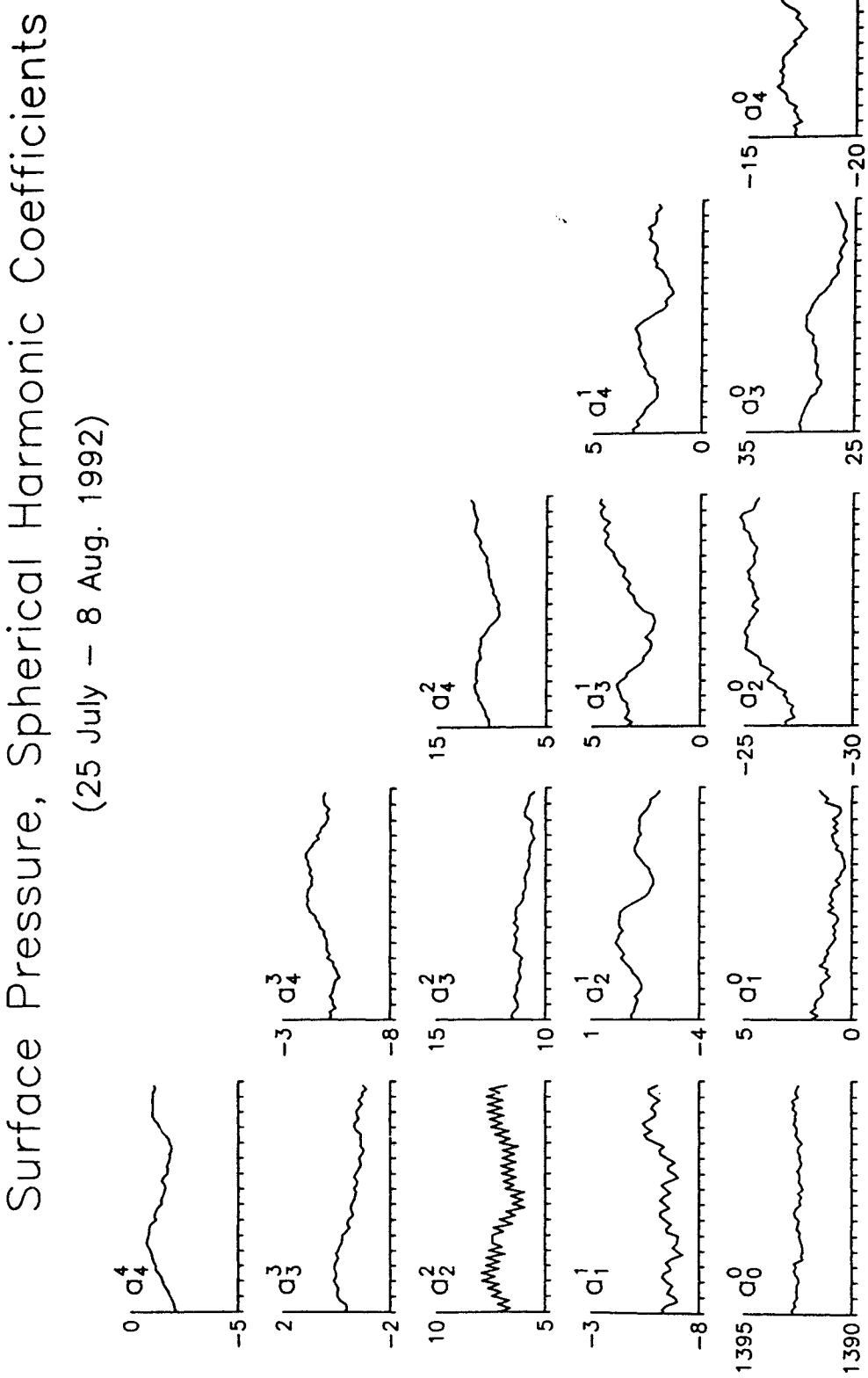

Figure 3a. Values of real coefficients of a triangular truncation (to degree 4) of a spherical harmonic expansion of the 6-hourly NMC surface pressure field. Units are hPa. The value of a_0^0, when divided by $2^{1/2}$, yields the global mean pressure.

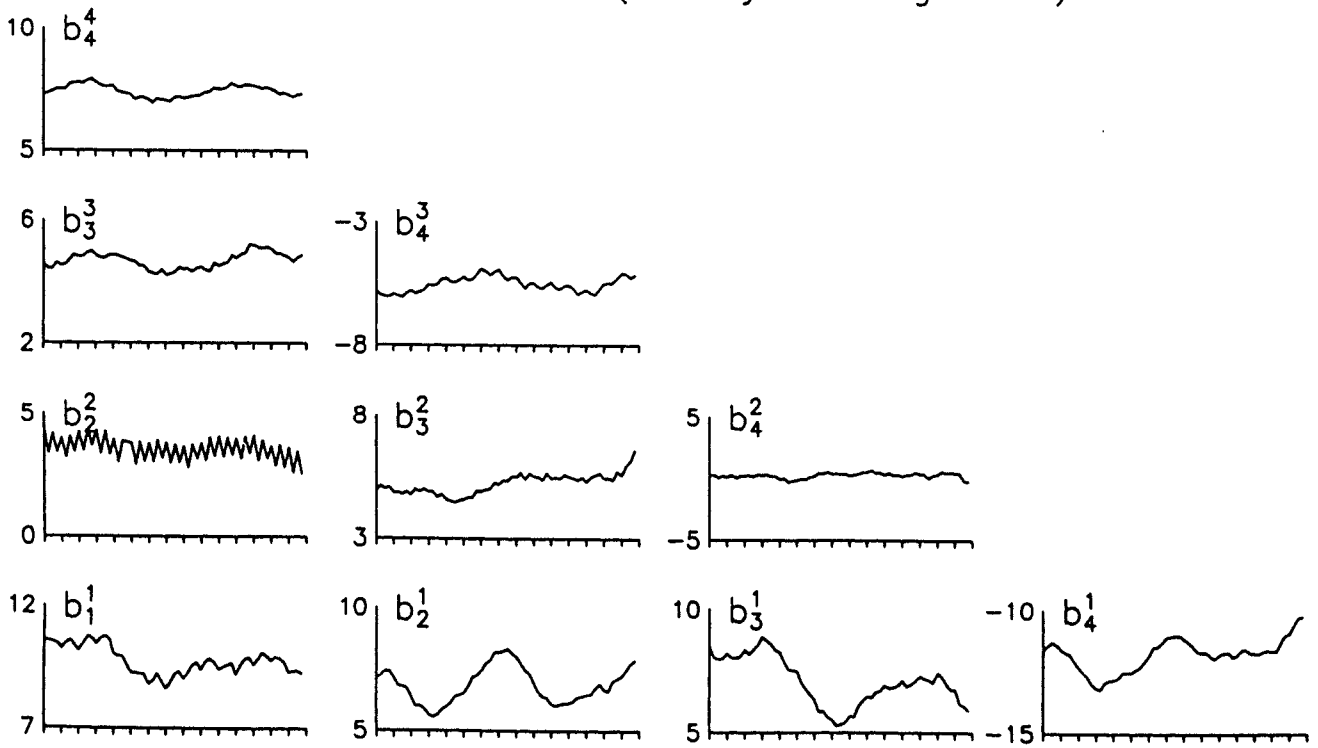

Figure 3b. Same as Figure 3a, but for imaginary coefficients. The zonal terms are equivalent to zero and are not given.

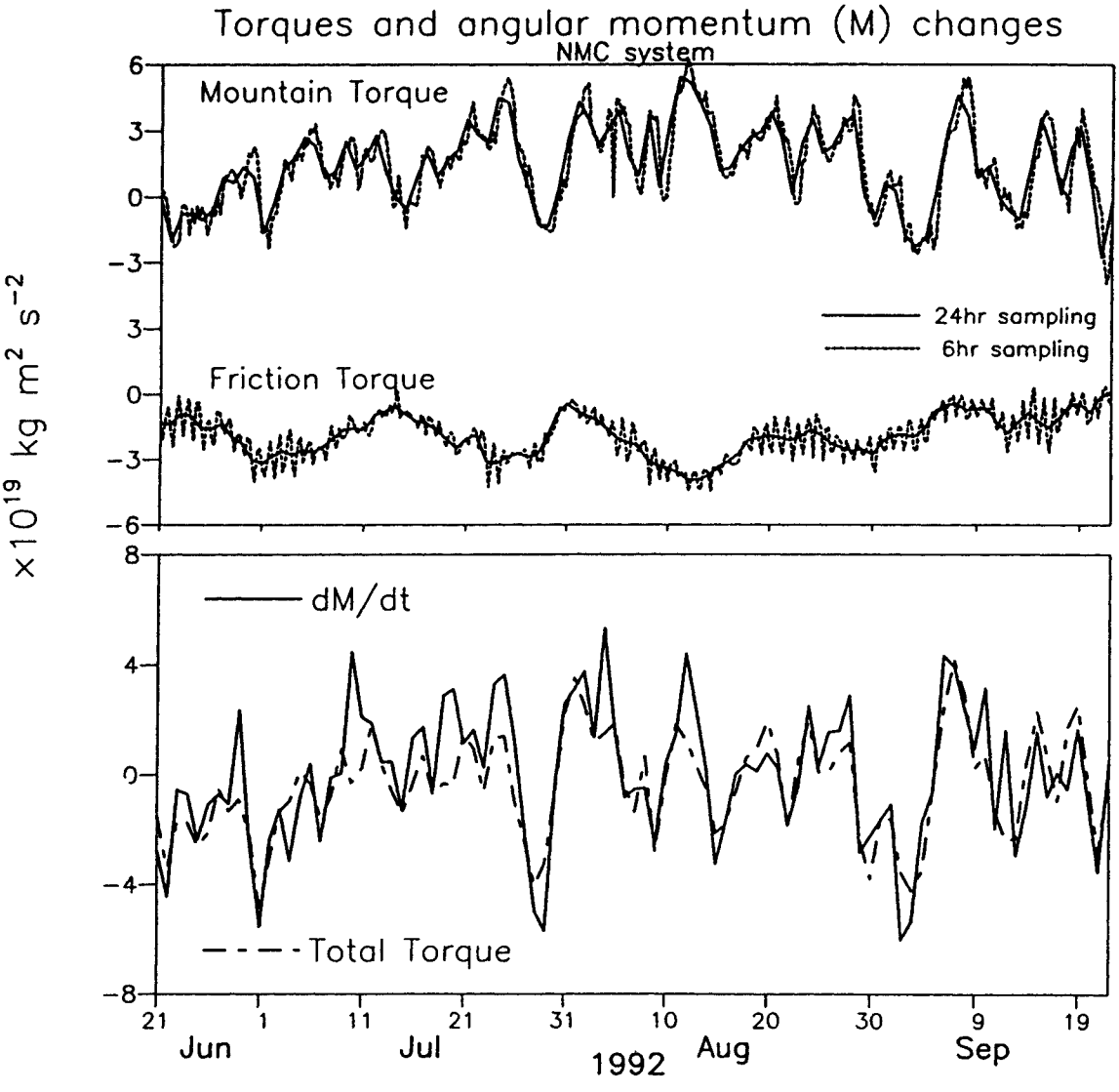

Figure 4a. (Top). Values of both mountain torque and friction torque, given every 6 hours, for the NMC analysis-forecast system. (Courtesy G.H. White of NMC). The daily means are given by the dashed lines. (Below) A comparison of the sum of the daily mean mountain and friction torque with the time derivative of axial angular momentum, proportional to the sum of the χ_3 wind and χ_3 pressure terms.

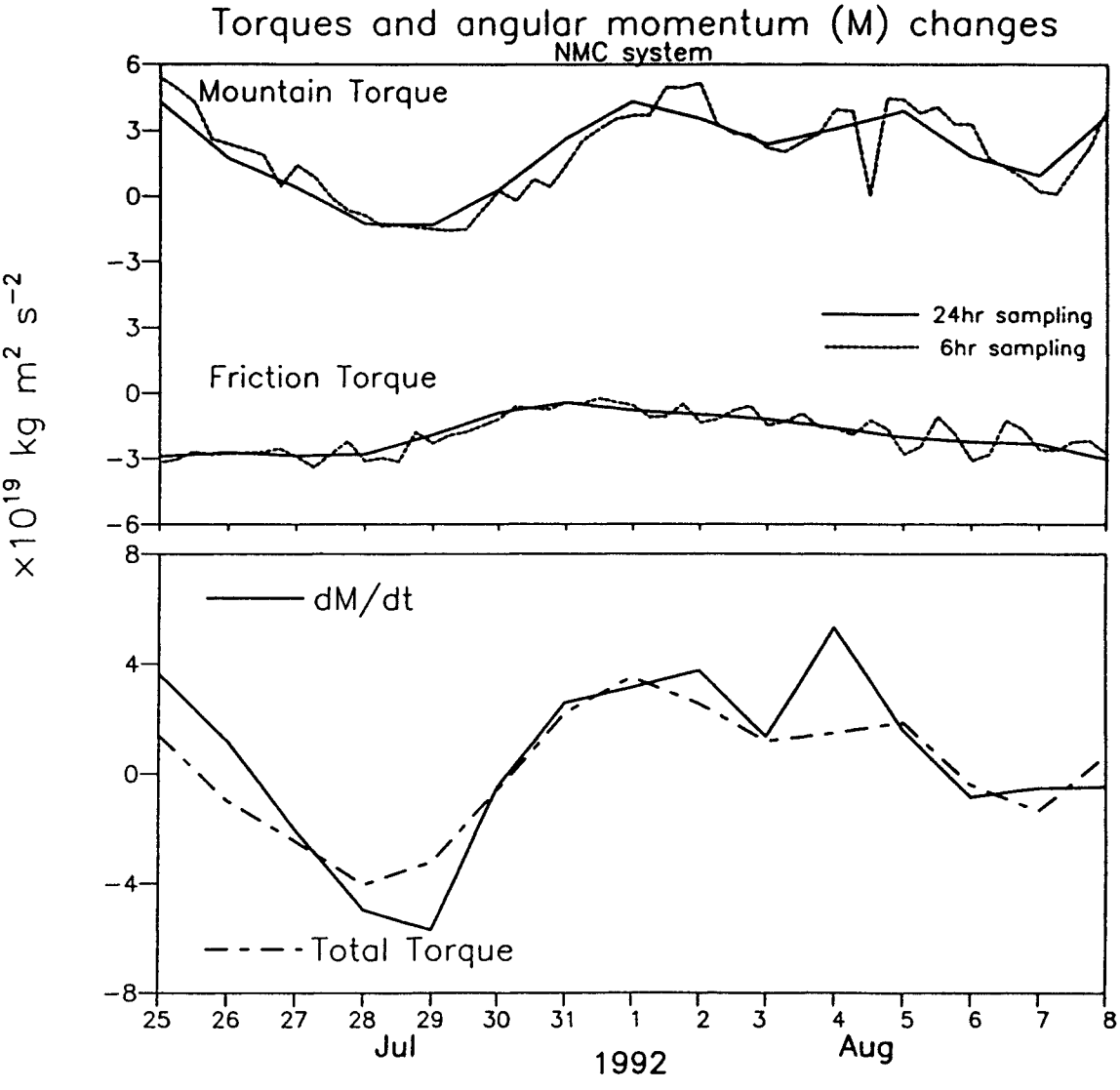

Figure 4b. Same as Figure 4a, but restricted to the intensive period of SEARCH'92.

5. Relevant Bilbliography

A discussion of the support for SEARCH'92 by the SBAAM was presented by Salstein et al. (1992) [Abstract in Appendix A] highlighting the intensive period. Further analysis of the local mechanisms responsible for rapid changes in atmospheric angular momentum, and hence in length of day, was presented by Salstein and Rosen (1993 and 1994). [Abstracts in Appendices B and C]. The particularly important regions for the intensive period were isolated to the low latitude southern hemisphere, where weather systems moving across the spine of the high Andes mountains of South America played a special role in accelerating the atmosphere during one phase (31 July-5 August) of a 1-2 week wave during this period.

6. References

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Salstein, D.A., R.D. Rosen, D.M. Kann, G.H. White, and A.J. Miller (1992) 'Activities of the IERS Sub-bureau for Atmospheric Angular Momentum in support of SEARCH'92', (abstract) *Eos. Trans. AGU*, 73 (43), Fall Meeting Suppl., 134.

Salstein, D.A., D.M. Kann, A.J. Miller, and R.D. Rosen (1993) 'The Sub-bureau for Atmospheric Angular Momentum of the International Earth Rotation Service: A meteorological data center with geodetic applications', *Bull. Amer. Meteorol. Soc.*, 74, 67-80.

Salstein, D.A. and R.D. Rosen (1993) 'Momentum variability and dynamic Earth-atmosphere interactions during SEARCH'92' (abstract) *Eos. Trans. AGU*, 74 (16), Spring Meeting Suppl., 103.

Salstein, D.A., and R.D. Rosen (1994) 'Topographic forcing of the atmosphere and a rapid change in the length of day', *Science*, 264, 407-409.

White, G. (1991) 'Mountain and surface stress torques in NMC analyses', Proceedings of the AGU Chapman Conference on Geodetic VLBI: Monitoring Global Change, U.S. Department of Commerce/NOAA/NOS, NOAA Technical Report NOS 137 NGS 49, Washington, DC, 262-269.

Appendix A

Abstract from the Fall Meeting of the American Geophysical Union, 1992

Activities of the IERS Sub-bureau for Atmospheric Angular Momentum in support of SEARCH'92

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During summer 1992, excitation functions for Earth orientation were received at the SBAAM from our four participating meteorological centers, the U.S. National Meteorological Center, the United Kingdom Meteorological Office, the Japan Meteorological Agency, and the European Centre for Medium-Range Weather Forecasts. These functions, which measure the role of the atmosphere in changing the length of day and polar motion, are based on global integrals of winds and surface pressures and are now being reported at either a 6- or 12-hourly frequency, depending on the center. The higher frequency data now available reveal a strong diurnal signal in the polar motion-related wind term, in particular. The ability to capture this signature, which has been attributed to atmospheric tides, suggests that useful information is provided by the meteorological analyses at all four synoptic hours, despite the smaller number of observations available at some of these hours.

The interfacial torques that are responsible for the transfer of axial angular momentum across the atmosphere's lower boundary have begun to be computed from the operational analysis-forecast system at NMC. These values, computed on a 6-hourly basis, consist of the so-called friction and mountain torques, which are caused, respectively, by tangential stress forces over land or ocean, and normal pressure gradient forces against topography. Although the stress torque is the less variable of the two over a season, it appears to contain a relatively large diurnal signal. As a check on the accuracy of the calculations, the sum of the two torques is found to closely match the independently computed time deriviative of global atmospheric angular momentum for this system.

Appendix B

Abstract from the Spring Meeting of the American Geophysical Union, 1993

Momentum variability and dynamic Earth-atmosphere interactions during SEARCH'92

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A special campaign to study Earth's rapid rotational variations and related atmospheric momentum variability was held in June-September 1992. As part of this effort, high temporal resolution angular momentum data from a number of meteorological data centers, especially during a two-week intensive period, were collected. The global axial component of atmospheric angular momentum during part of the SEARCH'92 period was observed to undergo oscillations on about a 10-day time scale, superimposed on a longer seasonal signal. Analysis in zonal belts indicates the importance of low and middle sourthern latitudes in contributing to the variance in these global signals. Further examination based on models and analyses of the U.S. National Meteorological Center reveals the relative importance of the two agents of dynamic momentum transfer, the frictional stress torque and the pressure-gradient mountain torque. In particular, the South American Andes region appears to have had special significance in producing a rapid transfer of momentum from Earth to atmosphere during the intensive period.

Appendix C

Abstract of Paper in *Science*: Vol. 264, pages 407-409, 1994

Topographic forcing of the atmosphere and a rapid change in the length of day

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ABSTRACT: During June-September 1992, a special campaign was held to measure rapid changes in Earth's rotation rate and to relate these to variations in the atmosphere's angular momentum, due principally to changes in zonal winds. A strong rise in both length of day and atmospheric momentum during a particular six-day subperiod is documented. For the first time, such a high-frequency perturbation is identified with a regional coupling mechanism. Mountain torques within the southern tropics appear to account for most of the rapid momentum transfer between the solid Earth and atmosphere, with those across the South American sector dominating.