JPL

COMBINATIONS OF EARTH ORIENTATION MEASUREMENTS: SPACE95, COMB95 & POLE95

by

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APPROACH

- **Use JPL Kalman Earth orientation Filter (KEOF) to combine independently determined Earth orientation measurements from all modern, space-geodetic techniques**

  - **Lunar laser ranging (results from JPL analysis center)**

  - **Satellite laser ranging (results from Center for Space Research at University of Texas at Austin)**

  - **Very long baseline interferometry [results from IRIS "Intensive" observational program (both NOAA & USNO analyses), NASA's Deep Space Network at JPL, NASA's Space Geodesy Program at GSFC, and the Navnet observational program of the US Naval Observatory]**

    - **NASA SGP series contains determinations based upon both NOAA and USNO multibaseline measurements**

    - **Therefore, no separate NOAA multibaseline series was used, and only that portion of the USNO multibaseline series that is independent of the NASA SGP series was used**

  - **Global positioning system (results from S10 and JPL analysis centers)**

- **Adjust bias and rate of each series so that they are in agreement prior to combination**

- **Remove leap seconds and tidal terms (when necessary) from UTI observations prior to combination**

- **Apply scale factor to the stated uncertainties of each series so that its residual has a reduced chi-square of one**

- **Delete outlying data points**

REMOVAL OF **UT1** TIDAL TERMS

- Yoder *et al.* [1981] model **used to remove effect on UTI of all long period (fortnightly and longer) solid Earth tides**

- Dickman [1993] model **used to remove effect on UT1 of ocean tides at** *Mf, Mf', Mm,* **and** *Ssa* **tidal frequencies**

  - The Dickman [1993] corrections to the Yoder *et al.* [1981] model were actually removed since the Yoder *et al.* [1981] model already includes the effects of an equilibrium ocean

- **Herring [1993] empirical model used to remove effect of semi-diurnal and diurnal ocean tides on NOAA's IRIS "Intensive" UT1 values**

  - Full amplitude of Herring [1993] model removed from NOAA's IRIS "Intensive" UT1 values since these tidal terms had been added back and are included in the released NOAA IRIS "Intensive" UT1 values

  - Subdaily tides were not removed from any of the other series used since none of them, including the USNO IRIS "Intensive" series, had these tidal terms added back to them

ADJUSTMENTS TO DATA ' "

- **For purposes of uncertainty scale factor determination, bias-rate adjustment, and data outlier elimination, an iterative, round-robin procedure was employed wherein each series was compared, in turn, to a combination of all other series**

  - **The three GPS and the two USNO series were not included in this iterative, round-robin procedure—see below**

- **Comparison is done, and results reported, in the natural reference frame of each series**

  - **For single station LLR results this is the variation-of-latitude ($\Delta\Phi$), UTO, indeterminable frame**

  - **For single baseline VLBI results this is the transverse (T), vertical (V), indeterminable frame**

  - **For all other results this is the usual UTPM (PMX, PMY, UT1) frame**

- **incremental bias-rate corrections and uncertainty scale factors thus determined during each iteration were applied to each series and the process repeated until convergence was achieved**

  - **Incremental bias-rate adjustments should converge to zero and incremental uncertainty scale factors should converge to one**

- **During the round-robin procedure, outlying data points were deleted**

  - **A data point was considered an outlier if its residual value was greater than three times its adjusted uncertainty**

  - **Before deleting any data points, four iterations were completed in order to converge on initial values for the uncertainty scale factors**

INCORPORATION OF GPS
AND **USNO** SERIES

- **GPS and USNO series not included in the iterative, round-robin scheme**

  - Not enough overlap with the other, independent series for reliable determination of bias-rate corrections

- **Bias-rate corrections and uncertainty scale factors were determined for the GPS and USNO series by separately comparing them to a combination of all other, independent data**

  - After the other series had had the bias-rate corrections and uncertainty scale factors applied to them that had been previously determined for them as described above

  - Only bias corrections were determined for the Scripps and JPL FLINN Analysis GPS series since their overlap with the other, independent series was not great enough to allow reliable rate corrections to be determined

  - JPL and SIO GPS data sets treated separately

- **Outlying data points (i.e., those whose residual values were greater than three times their adjusted uncertainties) were deleted during this procedure**

DATA COMBINED TO FORM SPACE95

Data Set Name	Data Type	Analysis Center	Data Span	Number Points
LLR (JPL; 18JAN96; $\Delta\Phi$, UT0)				
McDonald Cluster	LLR	JPL	10/05/76 −1 2/28/95	485
CERGA	LLR	JPL	4107/84 −12/1 4/95	538
Haleakala	LLR	JPL	2/1 0/85 - 8/1 1/90	65
UTCSR (CSR95L01)				
LAGEOS (PMX, PMY)	SLR	UTCSR	10/02/76 - 1/28/95	2025
DSN (JPL95R01; T,V)				
CA − Spain Cluster	VLBI	JPL	11/26/79 - 1/06/96	578
CA - Australia Cluster	VLBI	JPL	10/28/78 - 1/09/96	581
NASA SGP (GLB973f)				
Multibaseline	VLBI	GSFC	8/04/79 −1 2/28/94	1784
Westford − Ft. Davis	VLBI	GSFC	6/25/81 − 1/01/84	103
Westford − Mojave	VLBI	GSFC	3/21/85 - 8/06/90	13
NOAA (UT1MC31JAN95)				
IRIS Intensive (UT1)	VLBI	NOAA	4/02/84 −1 2/31/94	2356
GPS (SIO93P01; PMX,PMY)				
Scripps	GPS	SIO	8/25/9 1 − 5/31 /92	265
GPS (JPL95P02; PMX,PMY)				
JPL	GPS	JPL	6/01/92 - 1/27/95	817
GPS (PMX,PMY)				
JPL FLINN Analysis	GPS	JPL	1/28/95 − 2/1 0/96	365
USNO (N9604.EOP.INT 15FEB96)				
IRIS Intensive (UT1)	VLBI	USNO	1/04/95 − 2/1 0/96	269
USNO (N9604.EOP 15FEB96)				
Multibaseline	VLBI	USNO	12/28/94 − 1/07/96	106

ADJUSTMENTS TO DATA PRIOR TO THEIR COMBINATION INTO SPACE95

Data Set Name	Bias (mas)			Rate (mas/yr)			Uncertainty (σ) Scale Factor		
LLR (JPL; 18JAN96)	ΔΦ	UTO		ΔΦ	UTO		ΔΦ	UTO	
McDonald Cluster	-0.206	0.134		-0.568	-0.156		1.630	1.154	
CERGA	0.624	-0.055		0.136	-0.012		1.788	1.423	
Haleakala	-0.010	-1.454		-0.283	-0.170		1.549	1.692	
DSN (J PL95R01; T,V)	T	v		T	v		T	v	
CA – Spain Cluster	0.178	0.053		0.083	0.059		1.354	1.094	
CA – Australia Cluster	0.323	-0.046		-0.072	-0.050		1.371	1.098	
NASA SGP (GLB973f)	T	v		T	v		T	v	
Westford – Ft. Davis	11.357	0.576		1.055	-0.090		0.904	0.870	
Westford – Mojave	0.283	0.791		-0.028	0.008		2.326	0.954	
NASA SGP (GLB973f)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
Multibaseline	-1.203	-2.040	0.480	-0.154	-0.072	-0.121	2.226	1.963	2.192
USNO (15 FEB96)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
Navnet Multi.	-0.153	1.190	-0.705	0.193	0.099	0.043	2.012	1.602	1.783
NOAA (31 JAN95)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
IRIS Intensive	---	---	0.748	---	---	-0.072	---	---	0.933
USNO (15 FEB96)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
IRIS Intensive	---	---	-0.898	---	---	0.156	---	---	1.840
UTCSR (CSR95L01)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
LAGEOS SLR	-0.010	0.023	---	0.106	-0.049	---	0.849	0.743	---
GPS (SIO93P01)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
Scripps	-1.091	-1.516	---	-0.027	-0.018	---	1.956	1.903	---
GPS (JPL95P02)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
JPL	-0.194	-0.259	---	0.057	-0.156	---	3.257	2.800	---
GPS (FLINN Analysis)	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
JPL	0.450	0.219	---	-0.027	-0.018	---	12.273	3.542	---

reference date for rate adjustment is 1993.0

ADJUSTMENTS TO BIAS, RATE, AND UNCERTAINTY OF OPTICAL ASTROMETRIC SERIES

Data Set Name	Bias (mas)			Rate (mas/yr)			Uncertainty (σ_n) Scale Factor		
	PMX	PMY	UT1	PMX	PMY	UT1	PMX	PMY	UT1
BIH	-2.193	0.598	-8.083	1.581	0.583	5.409	1.814	1.595	1.860
LS	-56.990	3.603	---	0.601	-0.694	---	2.000	1.594	---

reference date for rate adjustment of BIH series is 1980.0
reference date for rate adjustment of ILS series is 1970.0

ADJUSTMENTS TO ANNUAL TERMS OF OPTICAL ASTROMETRIC SERIES

Data Set Name	Coefficient of Sine Term (mas)			Coefficient of Cosine Term (mas)		
	PMX	PMY	UT1	PMX	PMY	UT1
BIH	-5.955	-6.688	5.274	-2.953	10.276	-0.911
ILS	-0.717	8.048	---	9.915	-10.608	---

reference date for adjustment of BIH series is 1980.0
reference date for adjustment of ILS series is 1970.0

SPACE95

- **Prior to final combination, each data set was placed within an IERS reference frame by applying to it an additional bias-rate correction that is common to all the data sets**

  - **A preliminary combination of all the adjusted series (including the GPS and USNO series) was first formed**

  - **This preliminary combination was then compared to the IERS combined series EOP(IERS) C 04 for the years 1984-1995 in order to obtain the additional bias-rate correction required to make it (and hence each of the individual series) agree in bias and rate with the IERS combination**

BIAS (mas)			RATE (mas/yr)		
PMX	PMY	UT1	PMX	PMY	UT1
0.010 ±0.011	-0.059 ±0.010	0.046 ± 0.016	-0.027 ±0.003	-0.018 ± 0.002	-0.009 ± 0.004

- **After final combination, leap seconds and tidal terms were restored to the UT1 values**

  - **Yoder *et al.* [1981] model used to add back full effect of all long period (fortnightly and longer) solid Earth tides**

  - **Dickman [1993] model used to add back ocean tidal corrections to the Yoder *et al.* [1981] model values at the *Mf, Mf', Mm,* and *Ssa* tidal frequencies**

  - **No diurnal or semi-diurnal tidal terms were added back**

- **Resulting combined Earth orientation series is designated SPACE95**

  - **Consists of values for PMX, PMY, UT1−UTC, their formal uncertainties and correlations**

  - **Spans October 6.0, 1976 to February 10.0, 1 996 at daily intervals**
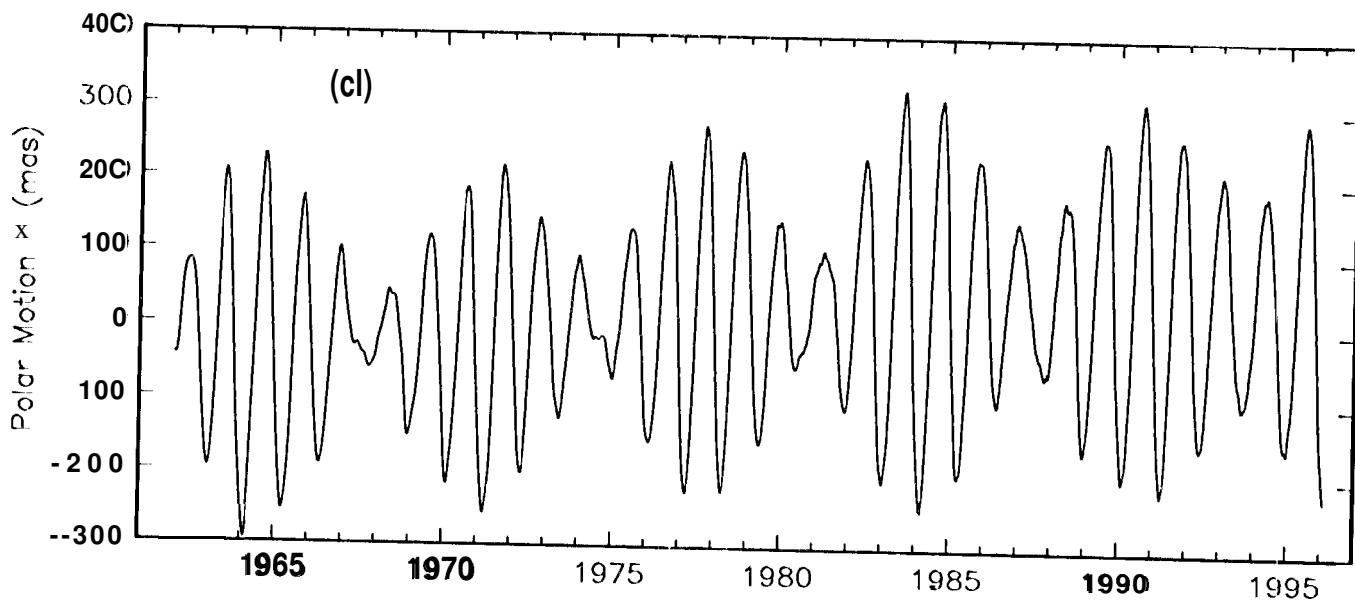
A COMBINED EOP SERIES: SPACE95

(a) Polar Motion X (mas)

(b) Polar Motion Y (mas)

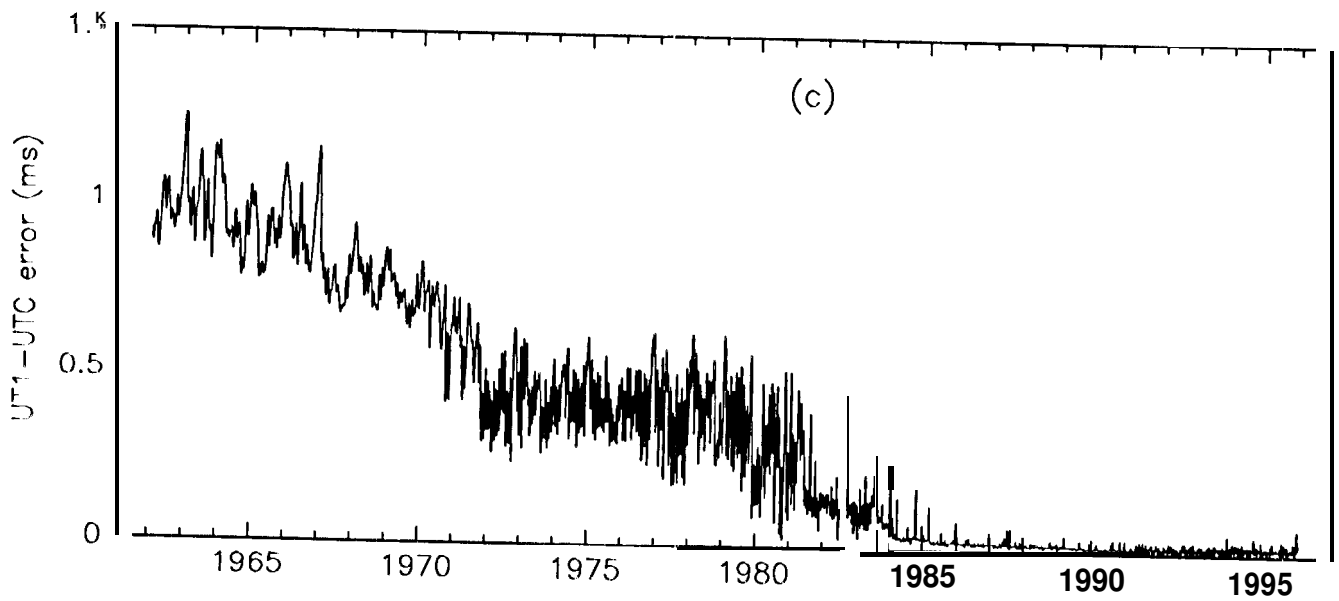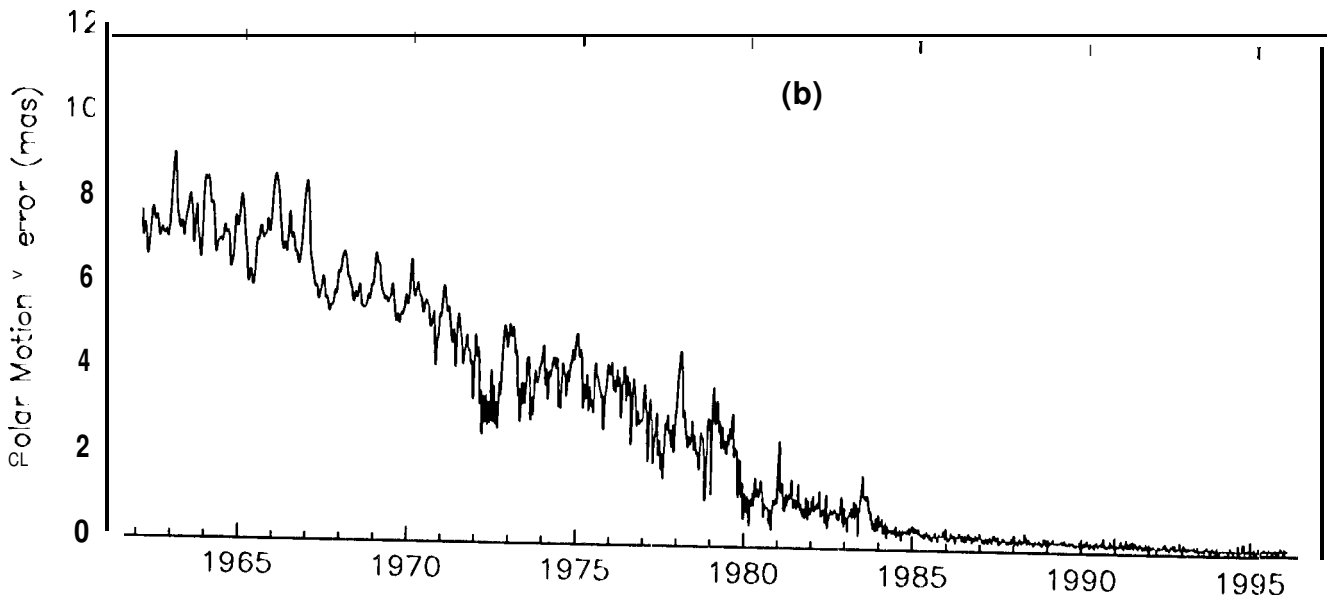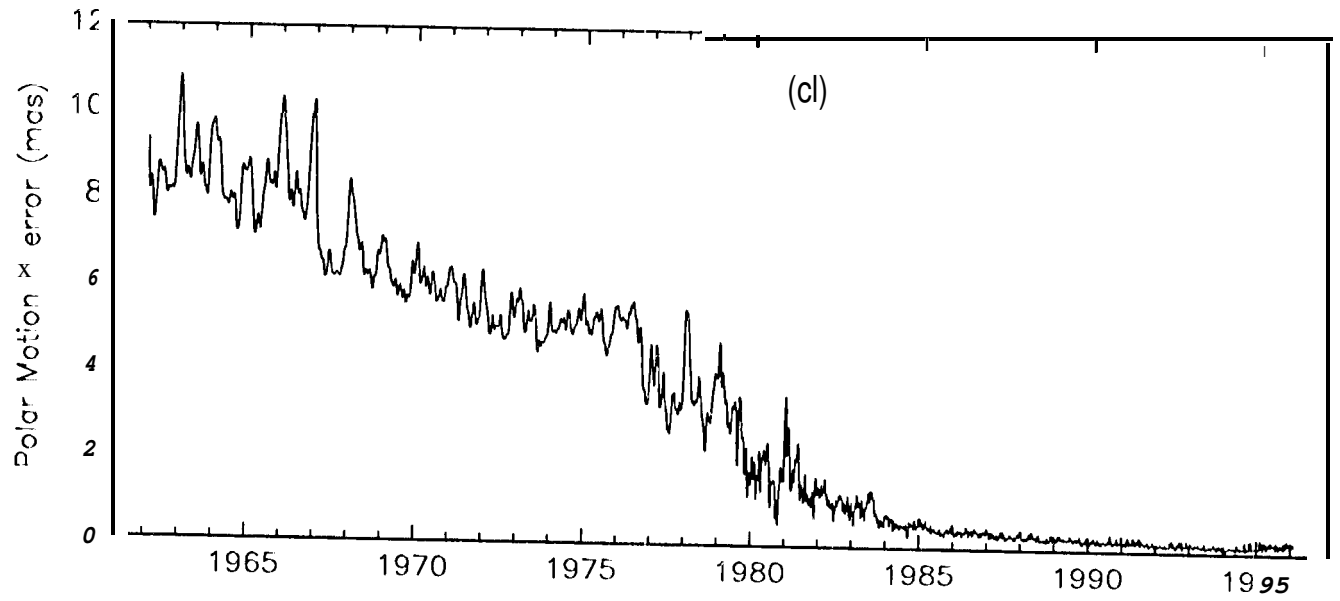(c) UT1−UTC (ms)
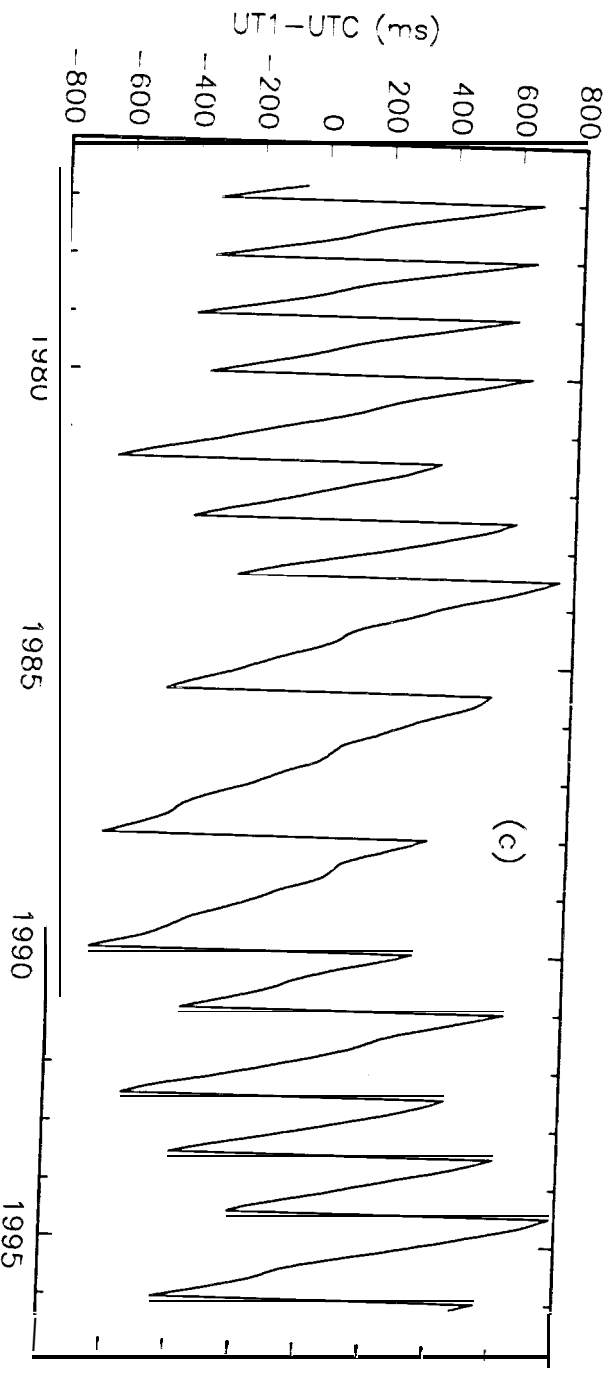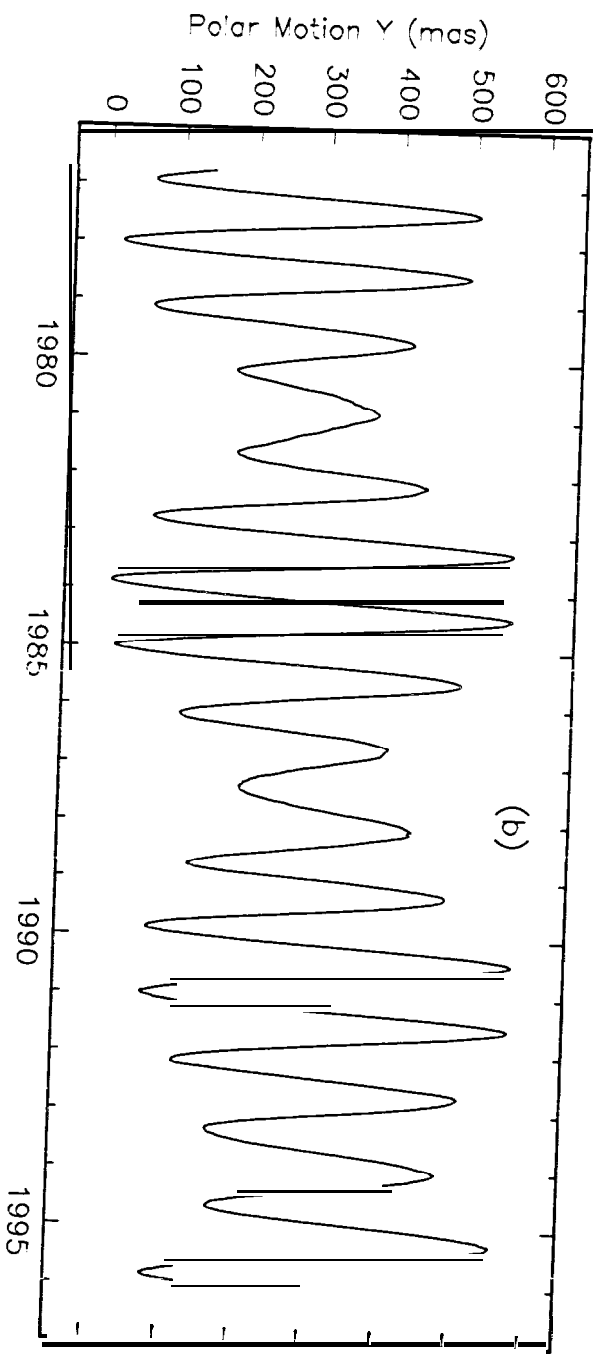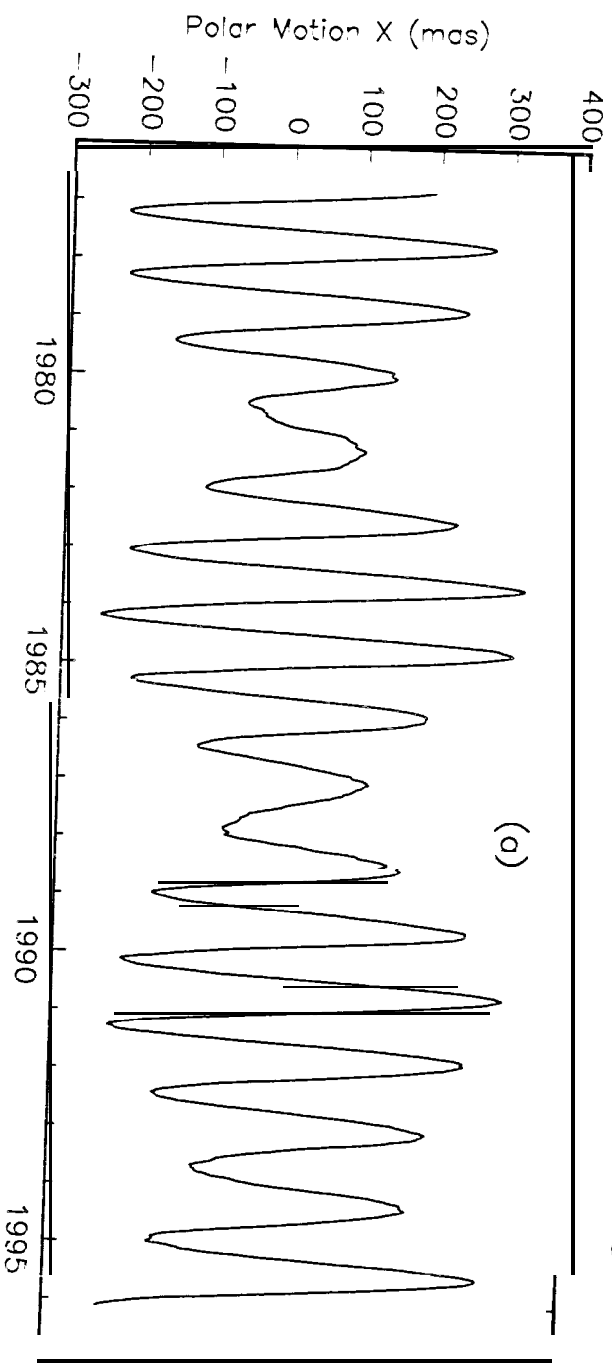
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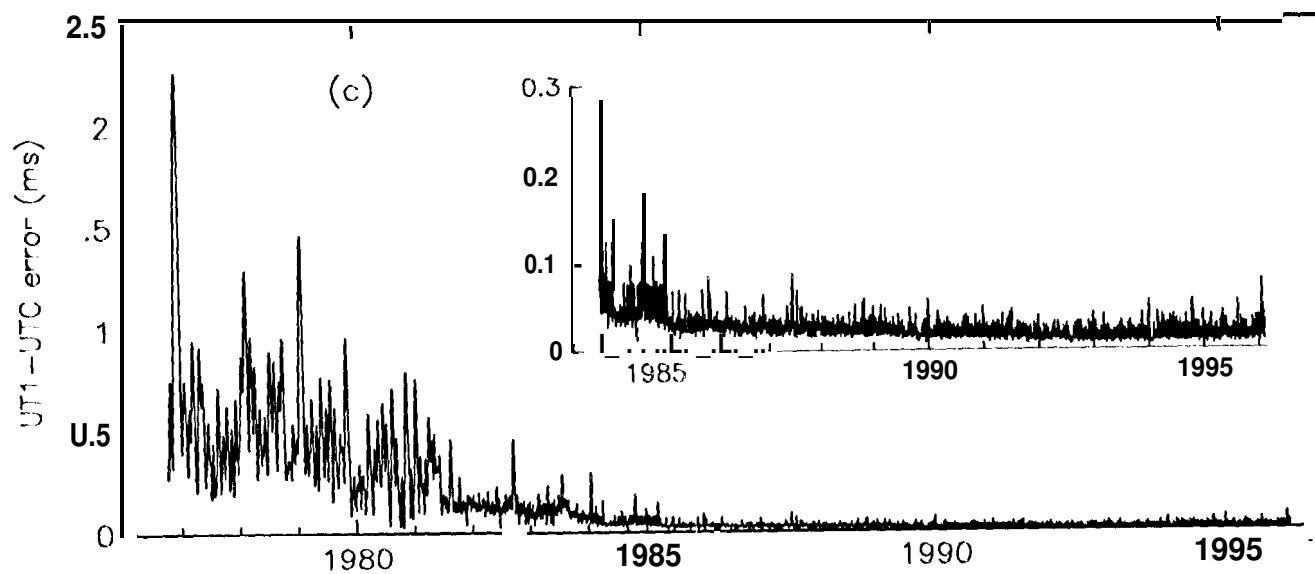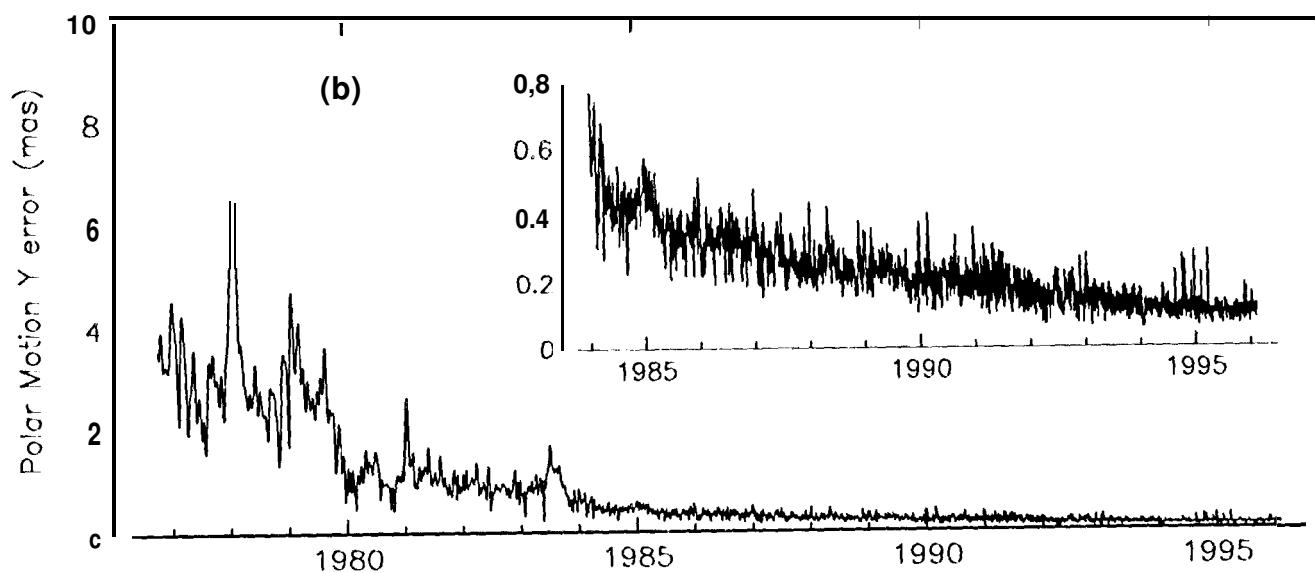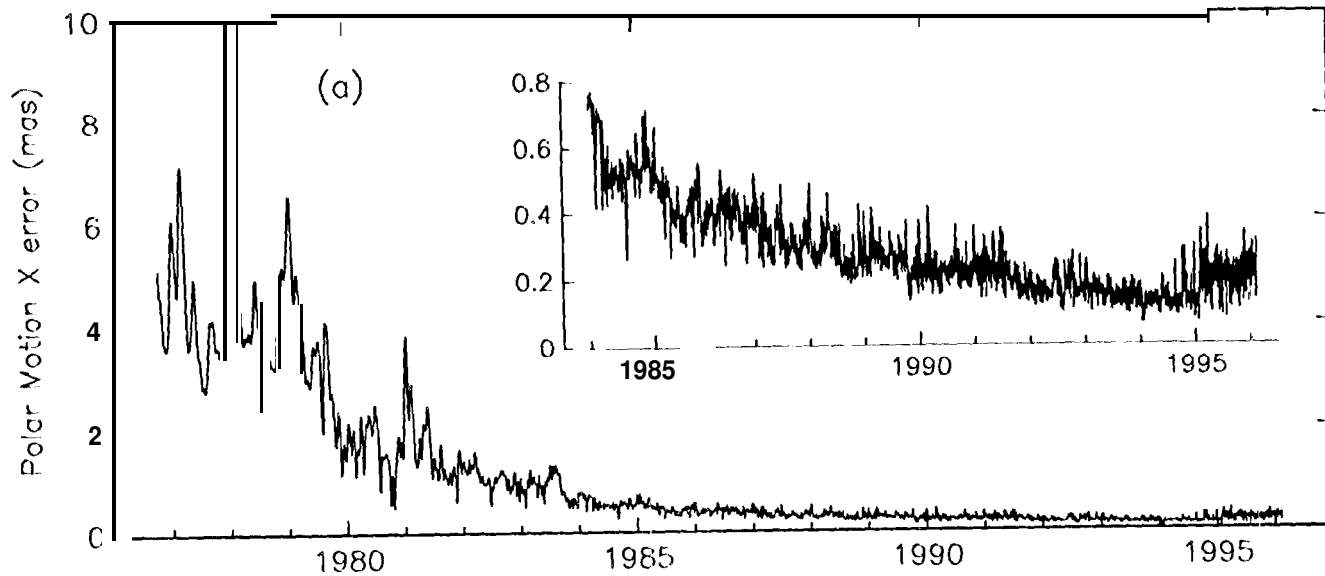
COMB95

- **Combination of optical astrometric and space-geodetic measurements**
  - BIH optical astrometric measurements (Li, 1985; Li and Feissel, 1986) of PMX, PMY, UT1–UTC spanning 1962.0 to 1982.0 at 5-day intervals
  - Space-geodetic measurements comprising SPACE95 spanning 1976-1995

- **BIH series adjusted prior to its combination with SPACE95**
  - Leap seconds and tidal terms removed from BIH UT1–UTC values
    - Yoder *et al.* [1981] model used to remove effect of all long period (fortnightly and longer) solid Earth tides
    - Dickman [1993] model used to remove ocean tidal corrections to the Yoder *et al.* [1981] model values at the *Mf, Mf', Mm,* and *Ssa* tidal frequencies
    - Amplitudes of fortnightly and monthly tidal terms attenuated prior to removal since BIH measurements are average values over 5 days (a significant fraction of these tidal periods)
  - Bias, rate, annual term corrections and uncertainty scale factors were determined for the BIH astrometric series by comparing it to SPACE95
    - BIH annual term adjusted because optical astrometric measurements are known to be susceptible to seasonally varying systematic errors
  - Outlying data points were deleted

- **COMB95 obtained by combining adjusted BIH series with SPACE95**
  - Consists of values for PMX, PMY, UT1–UTC, their formal uncertainties and correlations spanning January 20.0, 1962 to February 6.0, 1996 at 5-day intervals
  - Leap seconds and tidal terms were restored to UT1 values
    - Yoder *et al.* [1981] model used to add back full effect of all long period (fortnightly and longer) solid Earth tides
    - Dickman [1993] model used to add back ocean tidal corrections to the Yoder *et al.* [1981] model values at the *Mf, Mf', Mm,* and *Ssa* tidal frequencies
    - No diurnal or semi-diurnal tidal terms were added back
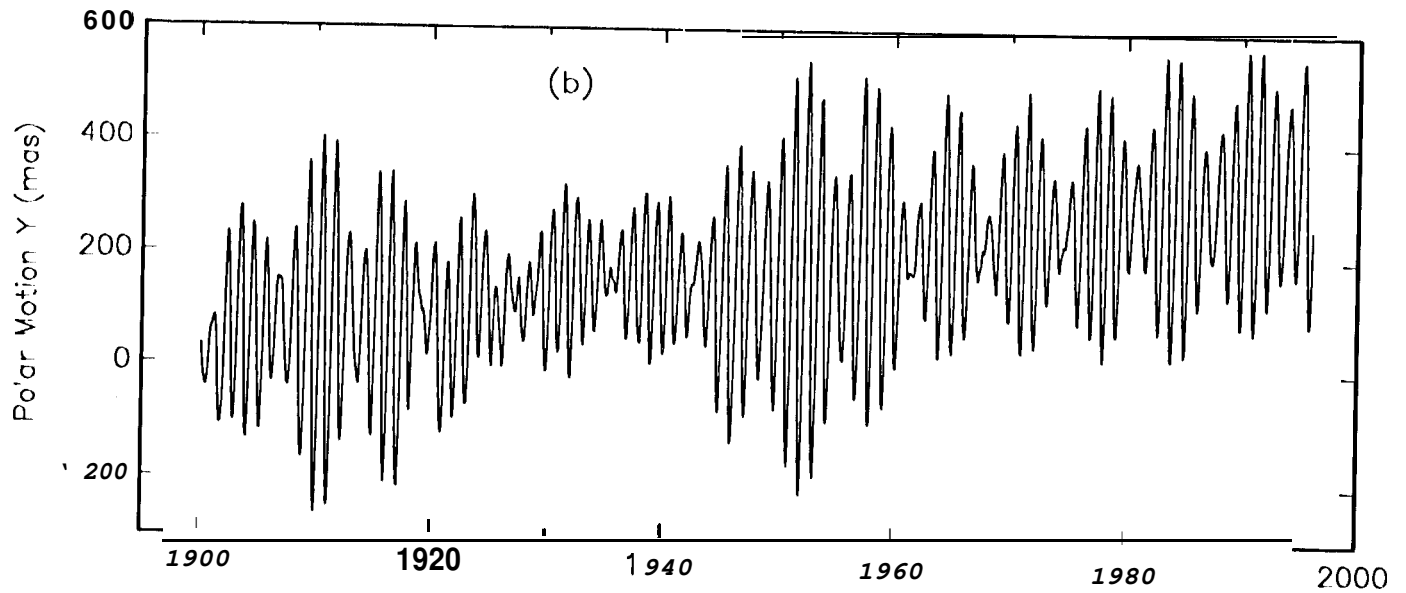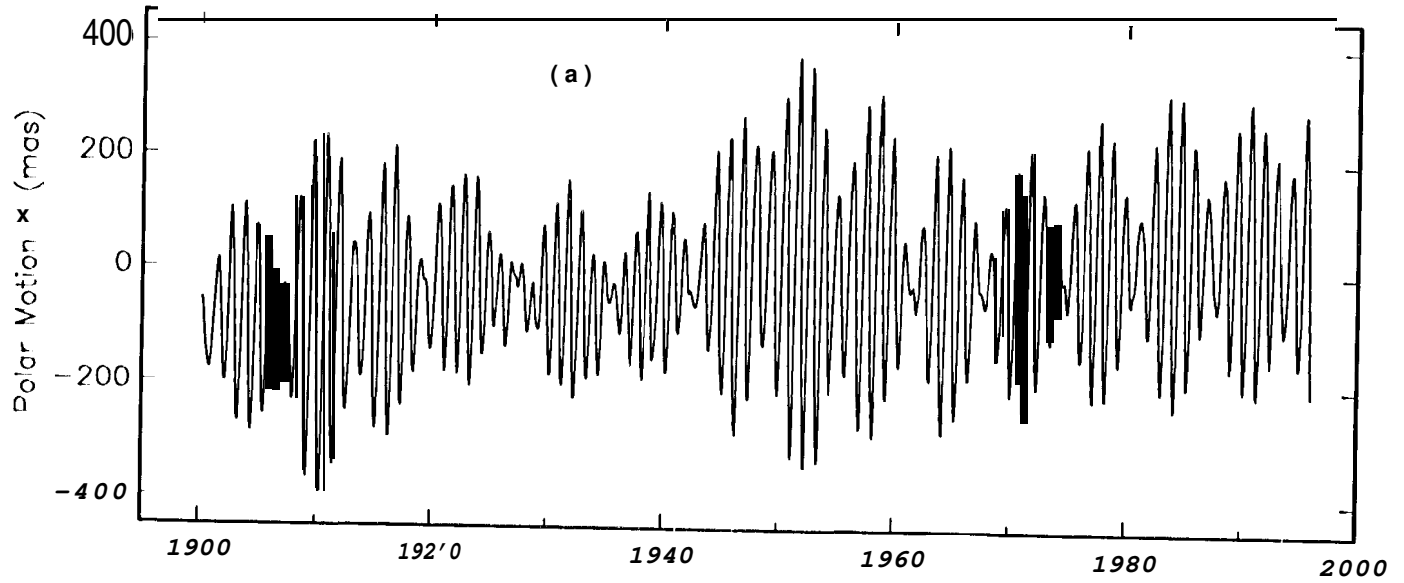
A COMBINED EOP SERIES: COMB95

A COMBINED EOP SERIES: COMB95

(cl)

(b)

(c)
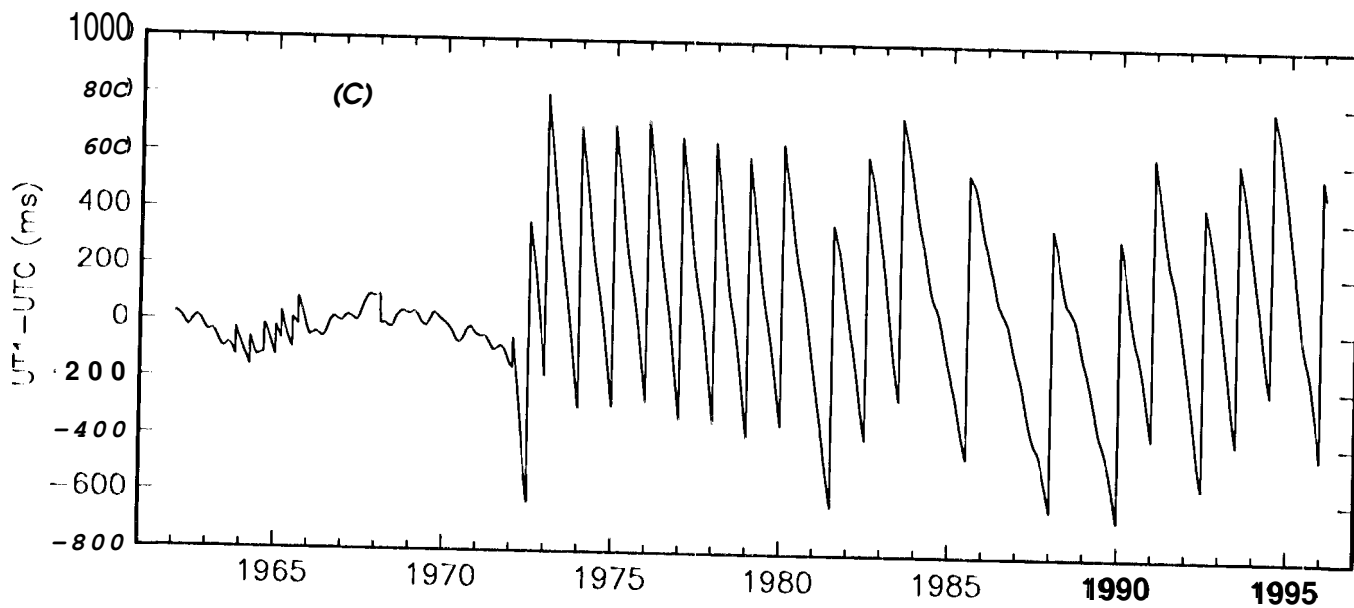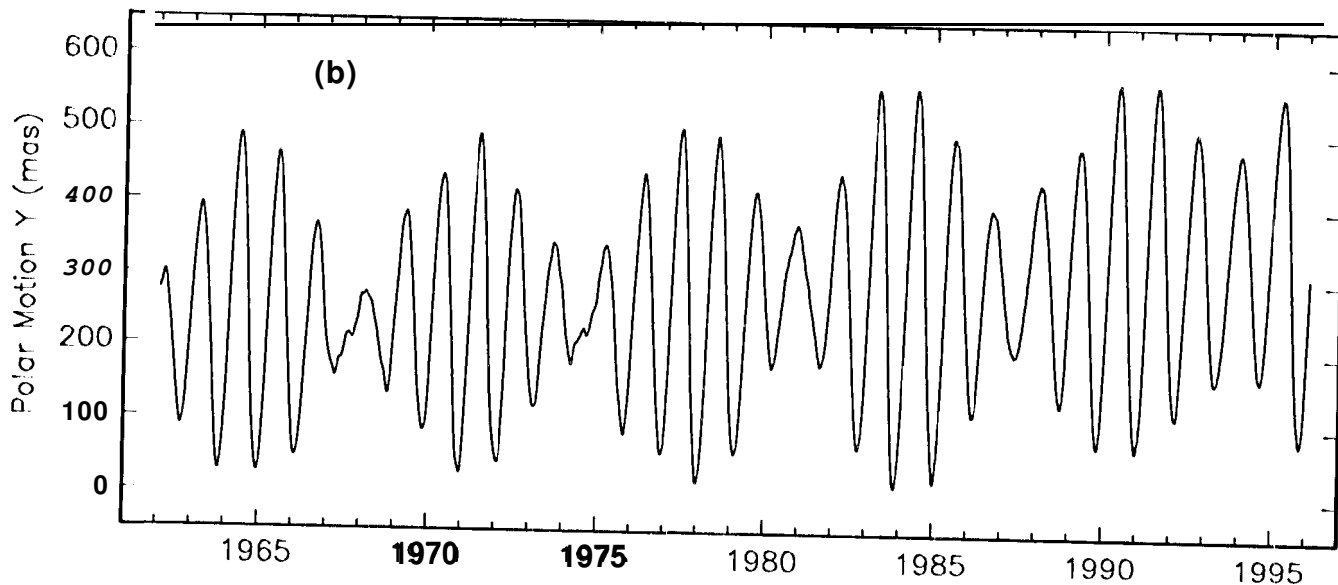
POLE95

- **Combination of optical astrometric and space-geodetic measurements**

  - **International Latitude Service (ILS) optical astrometric measurements of PMX and PMY spanning 1899.8 to 1979.0 at monthly intervals**

  - **Optical astrometric and space-geodetic measurements comprising COMB95 spanning 1962-1995**

- **ILS series adjusted prior to its combination with COMB95**

  - **No uncertainties are given with the ILS polar motion measurements, so an initial uncertainty of 15 mas was assigned to each of the ILS values**

    - **Since this assigned uncertainty is later adjusted, its initial value is arbitrary so long as it is not zero**

  - **Bias, rate, annual term corrections and uncertainty scale factors were determined for the ILS optical astrometric series by comparing it to COMB95**

    - **ILS annual term adjusted because optical astrometric measurements are known to be susceptible to seasonally varying systematic errors**

  - **Outlying data points (those whose residual values were greater than three times their adjusted uncertainties) were deleted**

- **POLE95 obtained by combining adjusted ILS series with COMB95**

  - **Consists of values for PMX and PMY, their formal uncertainties and correlations**

  - **Spans January 20, 1900 to January 21, 1996 at 30.4375-day intervals**

A COMBINED EOP SERIES: POLE95

A COMBINED EOP SERIES: POLE95

(a)

(b)