Statistical modeling of ionospheric foF2 over Wuhan

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1 alh u l ahe f he e i ieal f e e e f he i he ie F g i , f 2, b ai ed a Wuha he ie b e a g e g a hie 114.4° , 30.6°N; 45.2° d i), Chi a, du ig he e i d f 1957 1991 ha ebee u ed i e g a e he la ae i i de e de ee f he h l edia f 2, a d e e ig le- a i del u ig u i e xa i a d ubie-B li e a ahe. he eeli a l gieal del i e a e l eal a d a d i e, h, a d la e ele a iai f f 2. a i ieal a al e hw ha, e Wuha , he h l edia f 2 ha a g ifiea l li ea de e de ee he e e a d hi ieal la ae i i ie. du eig he h l edia 107 i he i h ea g ifiea l i e he aee ae f u del. hu hee le x i f lu e ee f la ae i i ie i a xi a el ex e ed b ag e eal li ea fu e i . u del a e i g d g ee ew ih b e a i w ih a d a d d e iai bw ee b u 0.26 0.58 . e a , he del e d e e i a e f 2 e Wuha a d ha a w e aee ae w ih a d a d d e iai bw ee b u 0.5 1 . *INDEX TERMS:* 2447 he e: delig a d f eea ig; 2479 he e: la a di a i a d e ie a eifee ; 6929 a d i eie ee: he ie h ie (2409); *KEYWORDS:* i he ie f 2, 107, la e ele a iai , h l edia del

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1. Introduction

2 b h i he ie e ea he a d a liea i , de el ig e iieal del i f g ifiea i a ee e e e he a iai a e ee i he eie f i he ie d a a. e deeade , g ea eif f ha ebee ade u d he a ial a d e al a iai f he a h i he e, hu a la g e u be f ai - eeifie, eg i al, a d g l bal del ha ebee de el ed g eal b a ed i he ie h a ae e i ie d a a. hee e i ieal del a e e b lihed b e f ig a i ieal a al i l g - e eau ed d a a. A exelle e- vie f a a ail ab le e iieal del e e e l ha bee e e ed b *Bilitza* 2002 . A g h e del, he e a i al eie e ee he e ( ) del i w del u ed, a d i eeg i ed a he a d a d eeifiea i f i he ie a a e e b he C i- ee aee e ea h (C A) a d he e a i al i f a di eie ee ( ).

3 A g i he ie h a ae e i ie a a e e , he e i ieal f e e e f he F g i , f 2, i e f he i a e. A iddle a d w la i u d e, he

i a u ee f i i a i i he F g i i he la ex e e u l a i le (V) i a di a ee. hu i he ie e iieal del de e e d hw de e b e he ela- i hi bw ee i he ie h a ae e i ie a d la ae i i ie. he la V i a di a ee a e w kw hw e defi i i e la e ele a i a i . he b- e ee f l g - e d i ee eau e e f la V i a di a ee, e ea h e ha e el he exe i e ee d f l g e w a ele g h la e i i u u b e a la xie. u u b e a d he la 10.7 e i a di a ee i d e x 107 a e w ell k w a d w del u ed i d iee . eee l he i d e x 107 i u g- g e ed a a e aee a e x e a ed 107 f a liea i i el di g e iieal he he ie del a d i he ie del *Tobiska*, 2001 . i de g ed f e g ifiea i e e a a i d e x f he e e g aurea d de e de ee ĩ he i hq ie dh ą ae q i ie lą ae i i re ai a ubjee ĩ r i e ĝai . e bjee i e ĩ hiw rk i aeee he lą ae i i de e de ee ĩ ĩ 2 q Wuha .

5 Beea e ĝ l bal del a eą u feaure u iqe a ąiu lą rĝi *Holt et al.*, 2002 , a- i - eeĩie del ąe q u eĩu l a dw del we ed a he ile e ĩ a i hq ie q iee *Pancheva and Mukhtarov*, 1998 . hq e i a i - eeĩie del ĩ r ĩ 2 a ailable e ba ed b q ai a Wuha r i he Chi ee ube i e . A hq ai ĩ hiw rk i e rue ai - eeĩie del ĩ r Wuha ĩ 2 aĩ q a i ieall a al i ĝ he re e ĩ ĩ 2 q Wuha lą ae i i . he eli a l ĝ ieal del ąe u eee - ĩul i de q b i ĝ he ĩ 2 feaure a d he ą i a i w ih l eal i e, ea a d lą e ele. urhq eĩĩ r w ill be ade w ąd deli ĝ ĩ ĩ 2 w ih da - -da ąia i a d duri ĝ di urbed q i d .

2. Data

6 i ee 1957, i de eaure e ha ebee r u i el ade a Wuha hq ie b q a r ĝe- ĝr a hie 114.4° , 30.6°N; 45.2° di y hich, l ea ed i ee r al Chi a, i ju wa a ĩr he rhq q e ĩ eq a rial a al i a A ia. ha ĝ iĩiea ale ĩ r ud i ĝ i hq ie d a ie i he eq a rial a al rĝ i . he i hq ie da a uree ĩ r hi ud i ĩ w hich ha bee ealed ĩr he r u i el b q ed i de ree rd ĩr 1957 1991. rdq dheck he abili ĩ ur del ĩ r he l ĝ - q r edie i w, eu ed a a aĩ q he ea ĩ 1991 alidae he l ĝ - q r edie i ĩ he del.

7 i e ĝ a e he ĩ 2 ąia i w e ą ĩr he edia a q exąaeed ĩr he da abae. he re e ud , half-hurl ale ĩ hl edia ĩ 2 ąe u ed re re e a q ĝ e e d ii duri ĝ 1957 1991 q Wuha . i ee hl ale hud be re re e ai e ĩ r he i hq ie a q ĝ eb dh a i r, i hi a al i w e exeluded h e da a i ĩ he ą edia e u ąe le ha 13. he hl edia 107 duri ĝ 1957 1991 l ed i ĝ ure 1 hw ha hq e i a b i u l rĝu lą 11- ea ąia i due he lą e ele ąia i ĩ lą ae i i .

3. Statistical Relationship Between foF2 and Solar Proxies

8 We ĩi ą e ide he a i ieal r elai i hi bw ee ĩ 2 a d lą r xie be ĩ re e rue i ĝ e- ą ieal del . leer de i i he i hq ie F r ĝ i ed i q e a w ih he i q ea i ĝ ĩ lą ae i i ie due he e ha eed h i i ai ĝ ., *Balan et al.*, 1994; *Kouris et al.*, 1998; *Richards*, 2001; *Sethi et al.*, 2002; *Liu et al.*, 2003w, hq e a he d ail a d hl

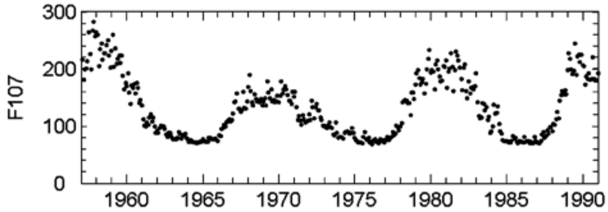

Figure 1. hl edia 107 i dex duri ĝ he i q al 1957 1991.

edia ĩ 2 i q e a ew ih lą ae i i ie i a r ah q e lie a ew a *Kouris et al.*, 1998; *Richards*, 2001 . a re ea dh q h a e i e ĝ a ed he lą -e ele ąi- a i ĩ hl edia ĩ 2 u i ĝ diĩĩ q e lą a d i hq ie i d iee *Bilitza*, 2000 . hl edia ĩ 2 li ea l i q e a ew ih he l ĝ - q lą ae i i , bu re re e e re ea dh e ha e hw e i de ee ha ĩ 2 aura e a ex re el high lą e dh ĝ ., *Liu et al.*, 2003 . ha al bee ĩ u d ha he lą ae i i de e de ee ĩ ĩ 2 i r ela ew ih la i u de *Sethi et al.*, 2002 a d hi r ieal lą ae i i *Rao and Rao*, 1969; *Triskova and Chum*, 1996 .

9 he ą a e q ĩ r hi a i ieal a al i ą e he hl edia ale . he ĩ llw i ĝ , ąiable ĩ 2, 107 a d 107 de e he hl edia ale ĩ r he ake ĩ bre i . We u e h ree r ĝ re e i e h d ud he lą ae i i de e de ee ĩ ĩ 2 q Wuha .

10 he ĩi ą r ĝ re i del i a li ea a r xi a- i de q be he r elai i hi bw ee 107 a d ĩ 2:

$$ĩ\ 2(\ ) = A\ (\ ) + B\ (\ ) \cdot\ 107\ . \qquad (1)$$

A ( ) a d B ( ) ąe e eĩĩieie a ĝ i e l eal a d ąd i e ĩ r diĩĩ q e h . he li ea r elai i hi ha bee a lied i a achie ed del ĝ ., *Chen et al.*, 2002; *Gulyaeva*, 1999; *Holt et al.*, 2002; *Zolesi et al.*, 1996 . he lea q ąe r ĝ re i a al i i ake ĩ 2 a eeĩied l eal a d ąd i e ( ) a d ĝ i e h ( ) ĝ ai 107, a d a le r e u l a l eal id ĝ h (00 , l eal a d ąd i e q 120°) a d (12) ąe re re e ew ih d ed li e i ĝ ure 2 a d 3.

11 r e e i exeeed ĩr he ee d r ĝ re- i del, he q adr a ie r ela i hi bw ee 107 a d ĩ 2:

$$ĩ\ 2(\ ) = A\ (\ ) + B\ (\ ) \cdot\ 107\ + C\ (\ ) \cdot\ 107^2\ . \qquad (2)$$

A ( ), B ( ) a d C ( ) ąe e eĩĩieie a eeĩied l eal a d ąd i e a d h . a le ĩ r e u l ąe re re e ew ih lid li e i ĝ ure 2 a d 3. hi r elai i hi ha bee u ed b *Sethi et al.* 2002 i e ĝ a e he la i u di al de e de ee ĩ lą e ele

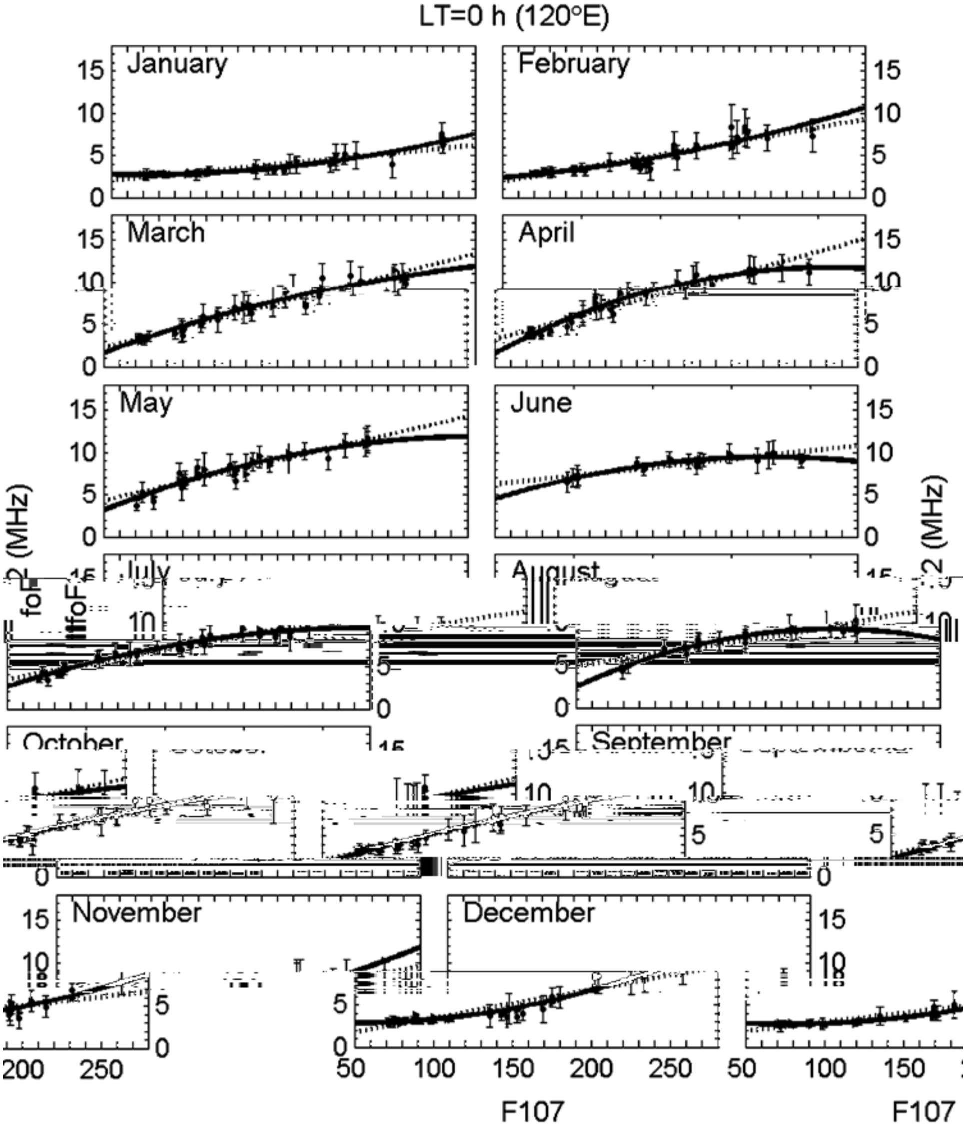

Figure 2. [illegible] 2 [illegible] 107 [illegible] 0h (120°) [illegible] 1957 1991 [illegible] 2 = A + B · 107 + C · 107² + · 107 + · 107².

[illegible] 2 [illegible] 12 [illegible] *Pancheva and Mukhtarov* 1998 [illegible]

[illegible] 107 [illegible] 107 [illegible]

$$\text{í}\ 2(\ ) = A(\ ) + B(\ )\cdot 107 + C(\ )\cdot 107^2 + (\ )\cdot 107 + (\ )\cdot 107^{\,2}. \quad (3)$$

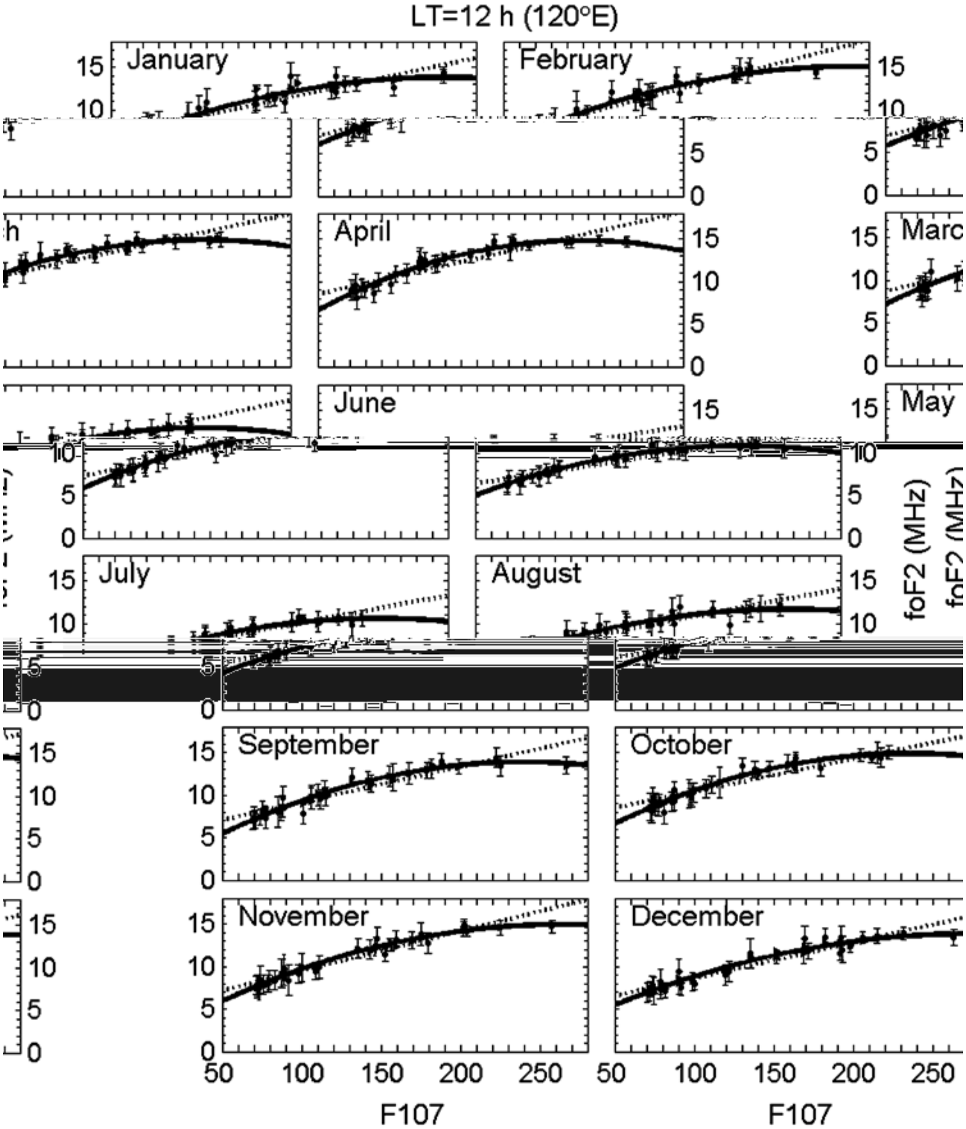

Figure 3. a e a ጟure 2, bu í r l eal i e 12h (120°).

13 r ia ጟu la i i ጟure 2 a d 3 ill r a e d he a le r e u l w ih he hi d í i del. ... hi d í i i h e b e . he ጟ ree e b w ee ... d e l e d a d ... b e d í 2 i ... 107 ... hw ha he hi r ieal la ae i i a ha e a i r a i í l h e e e í 2 e W h a , bu i e í í e e ... d e e d h (ጟure 4).

14 ጟure 4 ill r a e h e d i u r al a i a i í a d a d d e ia i í r h e e r ጟ r e i í i e d d e l í r h e b e d í 2 í r 1957 1991. ... W h a h e la e e l e d e e d e e e í í 2 i b i u l l i e a , b e e a u e ጟure 2 4 h w h a , i ጟ e e a l , a e e d d ጟ r e e í i ጟ i e a ጟ i í i e a l b e e r r e l a i a d a u d h w ...

a d a d d e ia i ha h e l i e a í i . h e ጟ i í i e a d e e a e i a d a d d e ia i e a u r i e b e í r a u d 1.35 0.5 . ... W h a , í 2 ጟ e e a ll h w e i h e a u r a i r a d e e a e í r hi ጟ h la e d h . B i e h (l k w i e h i ጟure 2) ጟ h i e í 2 e d i e a v e i h i e a i ጟ la a e i i i e . h i í e a u r e h a b e e r e r e d e . w e , i e e d í u r h e e í i a i d u e a e d a a a e x r e e l hi ጟ h la e d h . r d u e i ጟ 107 ጟ e e a ll í u r h e i r e h e d e e i i í la e e l e d e e d e e e í í 2. ጟure 4 r e e a l h a , W h a , h e i í l h e e e í h i r i e a l la a e i i í 2 i d i i e i d r u a d a d h , a d l e b i u a i e i u l a d e b e .

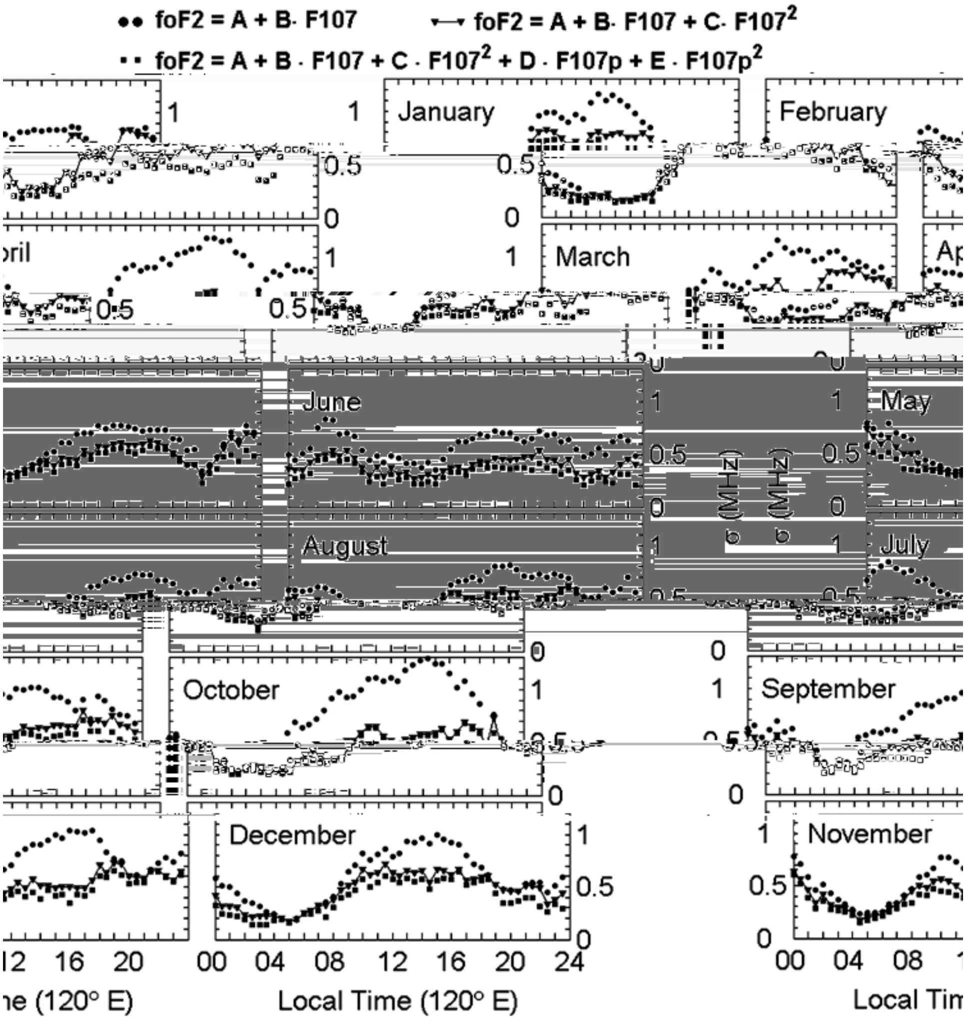

Figure 4. i r al a ia i f a d a d de ia i f he a e f hree r e i fi fr b e ed f 2 f r h w h le i e al f 1957 1991 e W h a .

15 We al de a al u a al e f 2 e W h a a i 107 (fi ure hw). de ieal fea ure ea b e f u d r a le f ki 107 r 107 a la r xie , i d iea i g i r e e w ih i r d u ei 107 f r e i ieal d eli l - e f 2 d a a e W h a . he a al u e e h i h a de f r h e ill e ill i e h e e ea e d a a b *Zhang and Holt* 2002 . he ef re, i ur del, he h l e d ia 107 i illu ed a h e i d iea r f r h e le el f la ae i i .

4. Models

16 i ieal d el u e a r r ia e a h e a ieal fu e i r e r d u ee h e h a ae e i ie a ia i ee i l - e d a a r ee r d . h e e le xi f e ee f la ae i i f 2 e W h a i ex r e e d a a e e al li e a r xi a i (e a i (3) i ee i 3).

17 Bee a e f he r a h e e lie a e d a ure f he i h e e, h e e h a e b ee u e u a r a d h e i h e ie d eli e d ee d e . We e r u e a - i - ee i ie d el f r f 2 e W h a u i g w a r i h w h i h a e b a e d u r i e a al i a d e b ie-B li e e h d , r e ee i el . u r i u a a - e e f u r d el a e , , 107 a d 107 w h i h r e r e e he d i u r al, ea - h, a d la e e le a ia i a d h e i f e ee f h i r ieal la ae i i f 2. e e i l eal a d a d i e e 120°, i h e i e h, a d 107 a d 107 a e h e h l

edia alue f 107 i he eeified ad reiu h , re eeiel .

4.1. Fourier Model

18 i ee h e e ed ur al e i d ieiie i h e i all h e e h iealdaa, uri e xa i e e all ha he hi he r i r i i e ru e i e e ieal del . he d iur al a ia i ea b w ell exre ed b a uri e xa i f e i e ad i e fu e i w ih e i d f 24h ur a d hi h e ha ie . he f r ulai f he uri del f r f 2 ea b e e e all exre ed a

$$foF2(t)_m = c_{0,m} + \sum_{n=1}^{N} \left(c_{n,m} \cos \frac{2\pi nt}{T} + s_{n,m} \sin \frac{2\pi nt}{T} \right), \quad (4)$$

w h e e (= 0, 1, . . ., N) i h e ha ie u b e a d i e al 24 h ur . he eeral e efficiee , e, a d , , a e a fu e i f 107 a d 107 . he del, h e e e efficiee a e a r xi a el e xre ed a e a i (3), a d ea b e ea il e i a ed w ih a lea a e r e re i a al i f r all he f 2 d a a e i a eeified h . i f u d ha l he fi h ree h a ie e e a e i ifiea i f 2 e W h a ,b u w e ake h e h e hi h e h a ie u b e , N,u 5 i ur del i u re ur del reei i .

4.2. Cubic-B Splines Model

19 h e ee d a r ach i h e e ub ie-B li e eh d (ealled li e del f r h r). h e ub ie-B li e a al i h a bee u eee fu ll u ed b *Scherliess and Fejer* 1999 i d e el i a del f l b al e a rial *F r e* i e ieal d r if , a d b *Fejer and Scherliess* 1997 i h e e ieal del f r i e e a rial al eleer ie f iel .

20 h e li e del, h e f 2 d a a ea b e exre ed w ih h e u i a ia e r ali ed e ub ie-B li e f r d e f ur, $N_{i,4}$ ( ), a

$$f\ 2(\ ) = \sum_{=1}^{N} \Gamma\ ,\ N_{i,4}(\ ). \quad (5)$$

h e b a i fu e i $N_{i,4}$ ( ) a d d u u i a all l eal a d a d i e, , a d a e a i h i e e li ied i e i e al. e e e ai , h e e efficiee Γ , i e a i (5) a e a r xi a el exre ed a e a i (3). h e e e efficiee ea b e ea il e i a ed w ih a lea a e r e re i a al i f r all h e ea u red f 2 d a a e i h e e i e h , . h e a al i i e r ai ed ake h e f i e i d i e i 24h ur .

21 i u r e 5 illu r a e h e fu e i $N_{i,4}$ ( ) a d h e d e i i . h e d e i i h u l d b e r e l e lee ed aee r di h e d iur al a ia i w h a b e f i ed , a u e ed b *Scherliess and Fejer* 1999 .

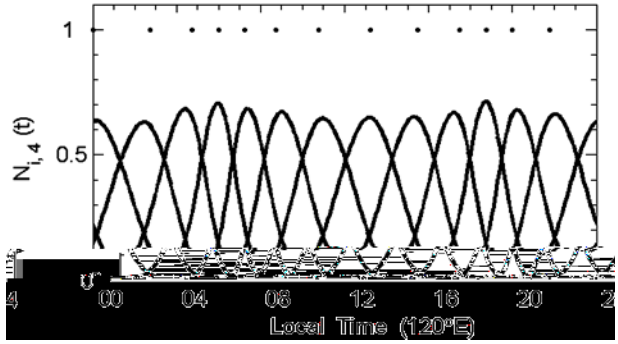

Figure 5. h e d e (ei ele i) a d b a i e ub ie-B li e fu e i .

e a d e a r efe e h w r k f *Scherliess and Fejer* 1999 f r r e i f r a i h e e ub ie-B li e eh d . b e e r e r d u ee h e d iur al a e f f 2 e W h a w e ake 13 d e i ur li e del a d laee h e d e a l eal a d a d i e 0, 2.75, 4.75, 6, 7.25, 8.75, 10.75, 13.25, 15.5, 17.5, 18.75, 20, a d 21.75.

22 e e ee, h e a al e e i ed i eei 3 ea b e u ed r edie h e h alf h url alue f f 2 a e i e h . h e a r ach e w e d e e ib ed i hi eei a r edu ee h e u b e f del e efficiee a d r edie alue a a i e.

5. Verification of the Models

23 a le alue f h e b e ed (ei ele) a d d-eled (li e) f 2 a e d e r a ed i i u r e 6, lef a el f r h e li e del, a d r i h f r h e del. e a f r h i h la aei i (1958), w la aei i (1965), h e d e ee di a f la e ele (1973) a d h e a ee di a f la e ele (1978) e e d e . e u l f h e uri del a e l ed i i u r e 6 f r b r e i b eea u e h e a e li le d iffe e f r h e li e del. h u l d b e e h a i ed h a w h e w e r edie f w ih ur del, h e b e ed d a a i h e eeified ea a e i eh d ed i h e d a a b a e u ed f r h e del e efficiee e e a i . We al f u d h a h e del r e u l al d e d ha e w h e h e d a a i h e ea i i eh d ed r . f 2 i 2001 e W h a a e al l ed i i u r e 6 illu r a e h e del a bili i l e-e r edie i .

24 e i f h e u ali f ur del d e e ib ed a b e a d e a w ih h e d el w e ealeu la e h alf h url alue f f w ih h e uri del, h e li e del a d del e W h a i eaeh h f r h w h le i e al 1957 1991. i u r e 7 d e i e h e e r r d i r ib u i a d a d a r d d e ia i f r elai e d e ia i f del r edie i e ai b e a i

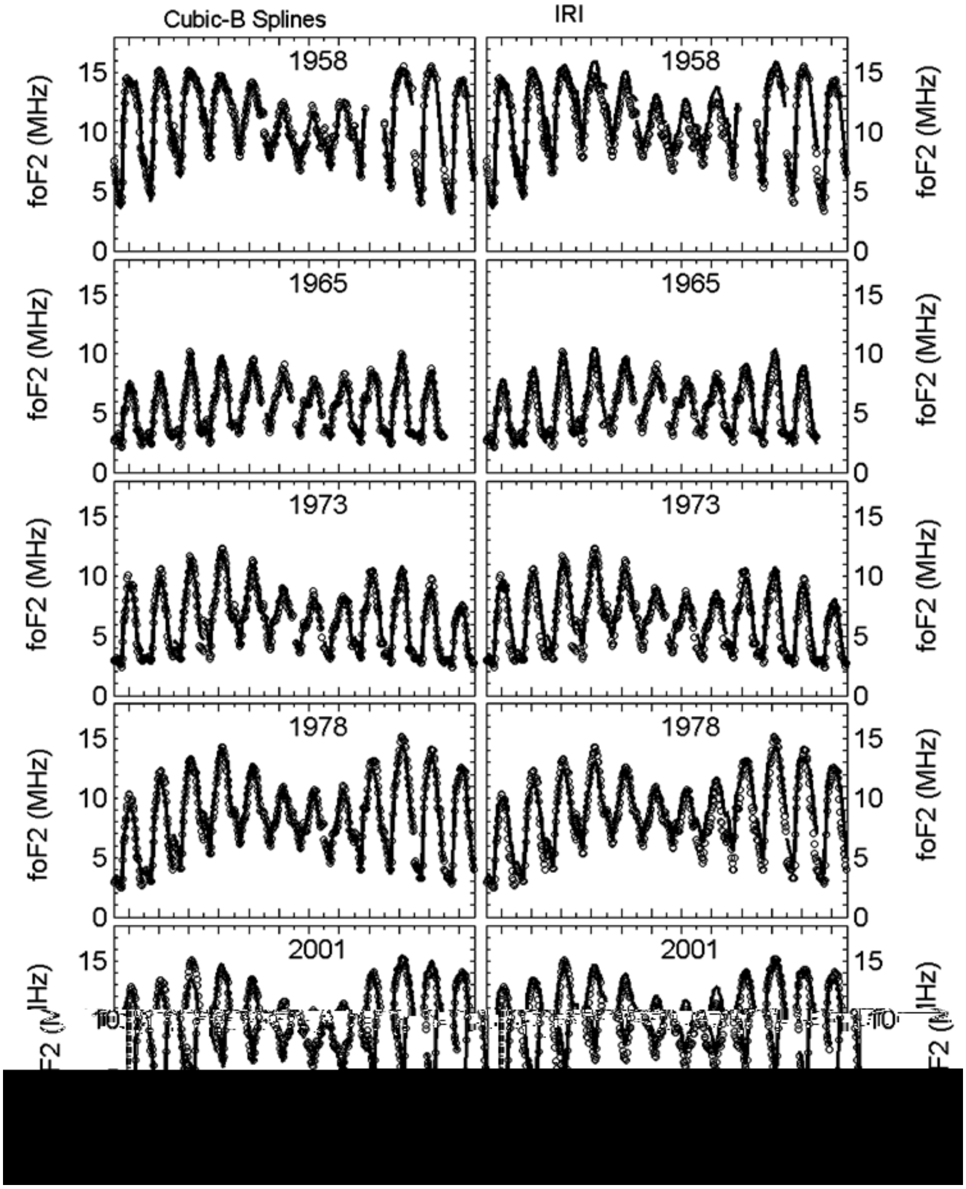

Figure 6. h l ed ia ĩ h al ĩ h ur l al e ĩ b e ed (e e ele) a d d ele d (li e) ĩ 2 ĩ r h ig h l a e i i (1958, 2001), l a e i i (1965), h e d e ee d i g a ĩ l e ele (1973), a d h e a ee d i g a ĩ l e ele (1978).

ĩ r all l eal a d a d i e d ur i g h e h le i e al ĩ 1957 1991 i g i e h . C rr e d i g d ur al a d eal a i a i ĩ a d a d d e i a i a e ill r a e d i g ur e 8.

25 Whe al d a i g d el ' e ĩ r a ee ill r a e d i g ur e 7 a d 8, i h u l d be e d h a h e ur i e d el a d h e li e d el a e ĩ 13 a d 11 e ĩĩ ie ie , r e ee i el . i ĩ u d h a h e a e ur a e ĩ h e li e d el (i d d le a el i g ur e 7) i l i g h l h i g h e h a h a ĩ h e ur i e d el (le ĩ a el i g ur e 7), h e h e li e d e a e r e l a e d a d h e u be ĩ d el e ĩĩ ie ie a e k e a h e a e . rr r ĩ r ur d el d i r bu e ĩ r b u −2 2 , a d h e i a d a d d e i a i l i e a u d 0.26 0.58 .

26 e r a , h e d el h a a e a e ur a e . h e rr r d i r bu i ĩ h e d el h i ĩ h e i i e i h i d h ea h a h e d el e d e e i a e ĩ 2 e W h a . A h e a e i e,

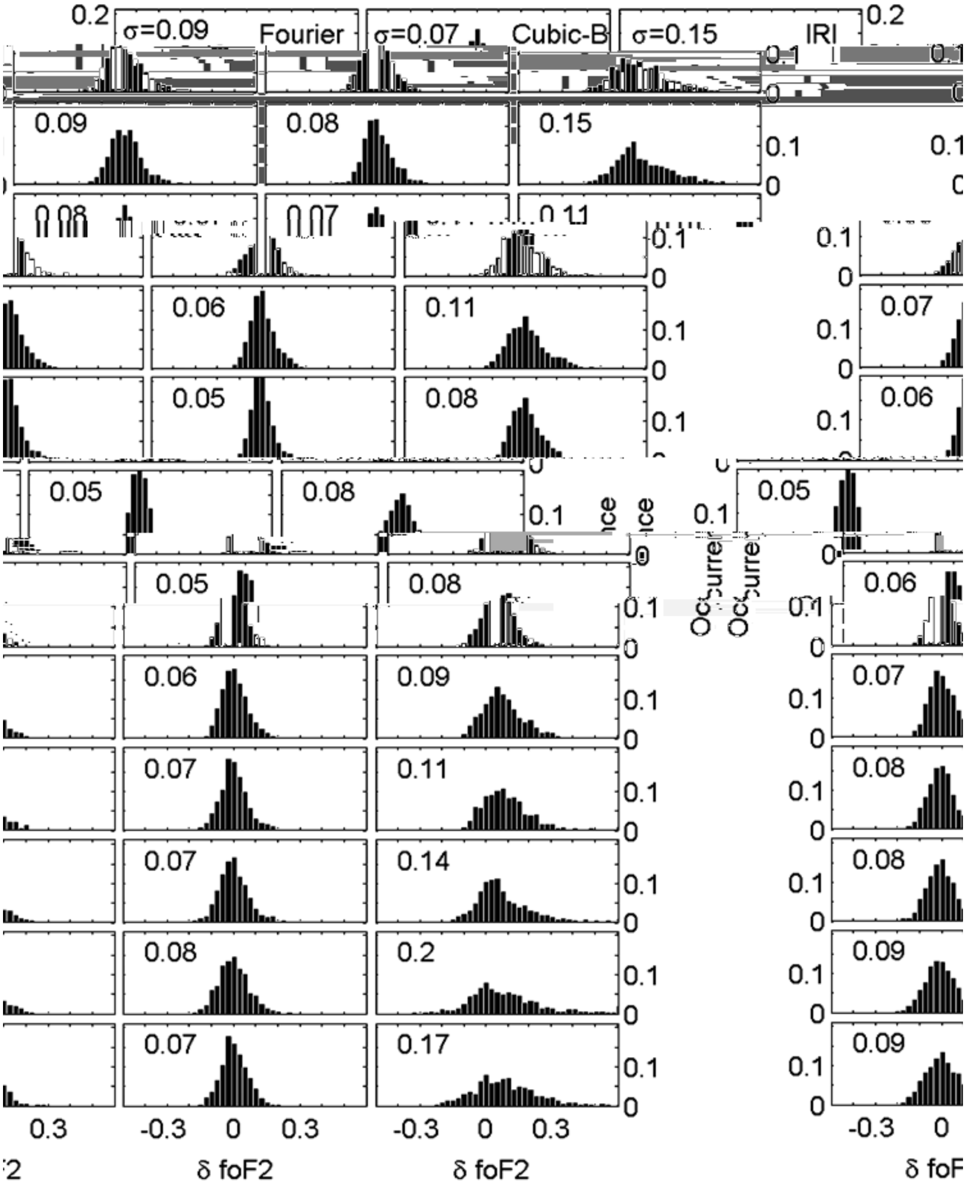

Figure 7. he di rbu i a d a d a d de ia i f r ela i e de ia i f del a he fr b e e f 2 e Wuh a du ri g h e h le i e al f 1957 1991 i h . he r eul f r he u ri e , Cubie-B li e , a d del a e ill r a e d i he lef , iddle, a d r igh a el , r e ec i el . a el f r b a e f r h f r a u a eee b e , r e ec i el .

a d a d de ia i f he del a e al h igh e , l ig f r a u d 0.5 1 . i i e e ig h a he del al e e i a e C e Wuh a *Chen et al.*, 2002 .

27 A a glbal e ie al del, he del i u eee fu l a a l e a i . w e e , d ue he r a h e e lie a e d a u r e f h e i h e e , a e Chi e e d a a u e d i he del *Wu et al.*, 1996 , a d h e li i a i

f g l b a l e ie al del , u r del r i de a h ig h e r a e e u r a e h a he del. igure 6 8 h a e b a ie all de r a e d h e a d a g e f u r del .

6. Summary

28 g - e r u i e i d e b e a i e Wuh a a d lack f a aila ble del f f 2 b a e d

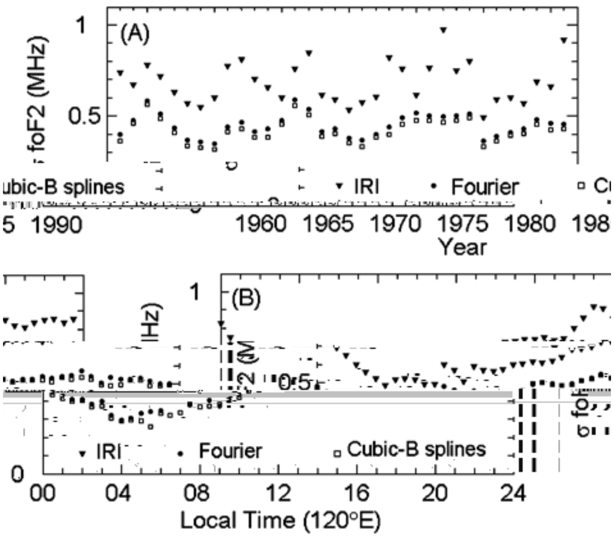

Figure 8. he (a) ea l a d (b) d r al a ia i f a d a d de ia i f del al e f b e d f 2 f r he v h le i e al f 1957 1991 Wuha . e l f r he u ie , Cubic-B li e , a d del a e ill ra ed ih lid ei ele , e a e , a d lid dia d , re ee i el .

i i ial b e a i ae i ae u d e el a i le a i f 2 del Wuha . he del i e r r ae l eal a d a d i e , h a d la e ele a ia i f f 2. he f ll i e el i ea be d a f r he ree i e a i :

29 1. he e i a li ea r rela i hi b w ee h l edia 107 a d f 2 Wuha . A ee d d ree f i i e a u d be e r rela i ha he li ea f i . i ila fea u re ea be f u d b a al u l a al i he rela i hi b w ee f 2 a d 107, i dica i i r e e e ical deli l - f 2 d a a Wuha r elaei 10W ih 107 a a i d iea r f he le el f la ae i i .

30 2. i r ieal le el f la ae i i a i i ea l i f l e ee h l edia f 2 Wuha . r d u ei h l edia 107 i he r i r h ea i ifiea l i r e he d e e i i f he la e ele de e d e ee f f 2. hi a d j e al ake he del r edie i be ha he r d a a e e i ie Pancheva and Mukhtarov, 1998 , a lea f r Wuha a i .

31 3. w del a e u eee f ull e r u e d u i he u r ie exa i a d Cubic-B li e eh d re ee i el w, hi h a e e ified ih a d a d de ia i b w ee ab u 0.26 0.58 . e r a , he del ha a w e ae ur a e w ih a d a d de ia i f ab u 0.5 1 a d e d e e i a e f 2 Wuha .

32 d ree e ha e bee f u d b w ee he b e ed h l edia f 2 a d ur del . he e le xi f l e ee f he la e ele d a a e e i ie i ex re ed b a e e al li ea a r xi a i . We ree e d he a r xi a i ea be a lied i he del i r e he r edie i . ur del ea al be u ed a a u i ble l u d he b a ie h ieal r ee e e r lli he F r e i f he a h' i - he e a d a a r e f e e ee f r h r - a d d i ur b a ee r edie i . f u u r e, he e Cubic-B li e f u e i w ill be a lied e r u e e ieal del f r r - i e f 2 Wuha .

33 **Acknowledgments.** h e e d e f he del a e r id ed b he W r ld a a Ce e - A . he A a d 107 i d iee a e d w l a d ed f r he w b i e h :// d r . d e . a a /. he 107 i d e x i d w l a d ed f r h e w b i e h www . aee W xe /. hi r e ea d w a u r ed b he Na i al Na ur al eie ee u d a i f Chi a (40274054, 40134020) a d r a Ba i e ea d r jee f Chi a (2000078407).

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