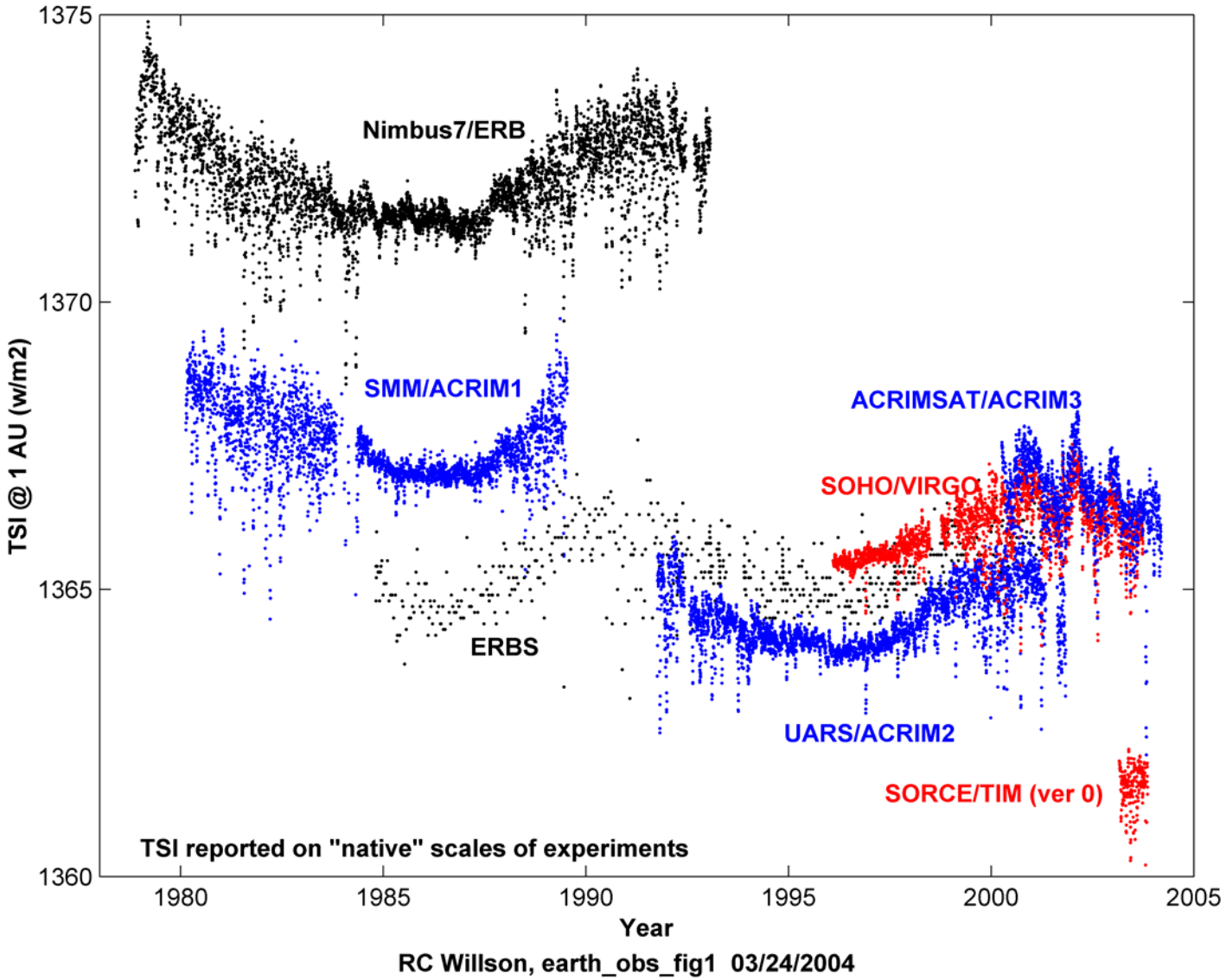
Total Irradiance:
Calibration Issues & Recent Results

Status of The Total Solar Irradiance (TSI) Observational Database

- **Continuous monitoring by *satellite* experiments conducted since late 1978**
- **Continuous monitoring since 1980 by *redundant, overlapping, satellite* experiments**
- ***Overlapping comparisons* facilitate contiguous results at mutual precision levels**
- ***Absolute uncertainty* varies by experiment with a lower limit of ~ *0.1 %***
- ***Internal traceability* of each experiments varies with ~ 3 ppm/year lower limit**
- ***Inter-experiment traceability* varies with ~ 50 ppm/decade lower limit**
- ***Scale differences* (of up to 0.4 %) likely due to systematic errors in sensor metrology**

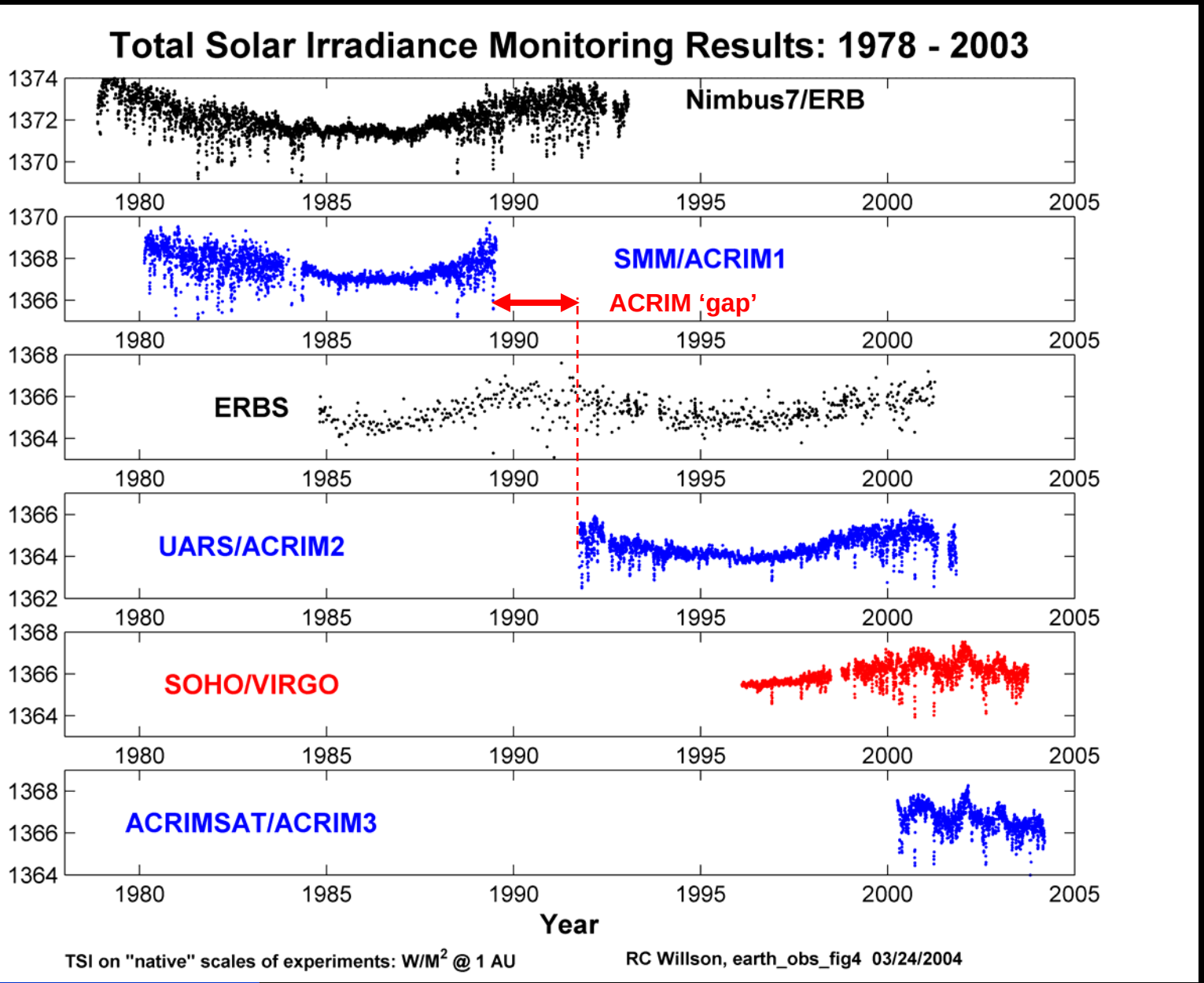

TOTAL SOLAR IRRADIANCE MONITORING RESULTS: 1978 to Present
1375
1370
1365
1360
TSI @ 1 AU (w/m2)
Nimbus7/ERB
SMM/ACRIM1
ACRIMSAT/ACRIM3
SOHO/VIRGO
ERBS
UARS/ACRIM2
SORCE/TIM (ver 0)
TSI reported on "native" scales of experiments
1980
1985
1990
1995
2000
2005
Year
RC Willson, earth_obs_fig1 03/24/2004

0.4 %

Critical Characteristics of TSI Monitoring Experiments

Experiment	PI Mode	Observing Frequency	Shutter Calibration Frequency	Electrical Calibration Frequency	Degradation Calibration	Solar Pointed
Nimbus7/ERB 1978 – 1993	Quasi	3 of 4 days 5 min/LEO orbit	None	2 weeks	None	No
SMM/ACRIM1 1980 - 1989	Yes	55 min/LEO orbit	1 min. cycle	Continuous	3-fold redundant Monthly	Yes
ERBS 1984 - 2000	No	5 min. every 14 days	30 sec. cycle	2 weeks	None	No
UARS/ACRIM2 1991 →	Yes	35 min/LEO orbit	1 min. cycle	Continuous	3-fold redundant Monthly	Yes
SOHO/VIRGO 1996 →	Yes	Continuous L1 Point Orbit	Partial shutter failure limits Calibration capabiity	Continuous	2-fold redundant, Hiatus sensor changes Degradation rate issues	Yes
ACRIMSAT/ACRIM3 2000 →	Yes	62 min/LEO orbit	1 min. cycle	Continuous	3-fold redundant Monthly	Yes
SORCE/TIM 2003 →	Yes	~ 55 min/LEO orbit	100 sec. cycle	Continuous	3-fold redundant Monthly	Yes

Color				
Impact on Observations	Degrading	Sub-optimal	Optimal	Optimum


Total Solar Irradiance Monitoring Results: 1978 - 2003
Nimbus7/ERB
SMM/ACRIM1
ACRIM 'gap'
ERBS
UARS/ACRIM2
SOHO/VIRGO
ACRIMSAT/ACRIM3
Year
TSI on "native" scales of experiments: W/M2 @ 1 AU
RC Willson, earth_obs_fig4 03/24/2004

ACRIM Composite TSI Approach

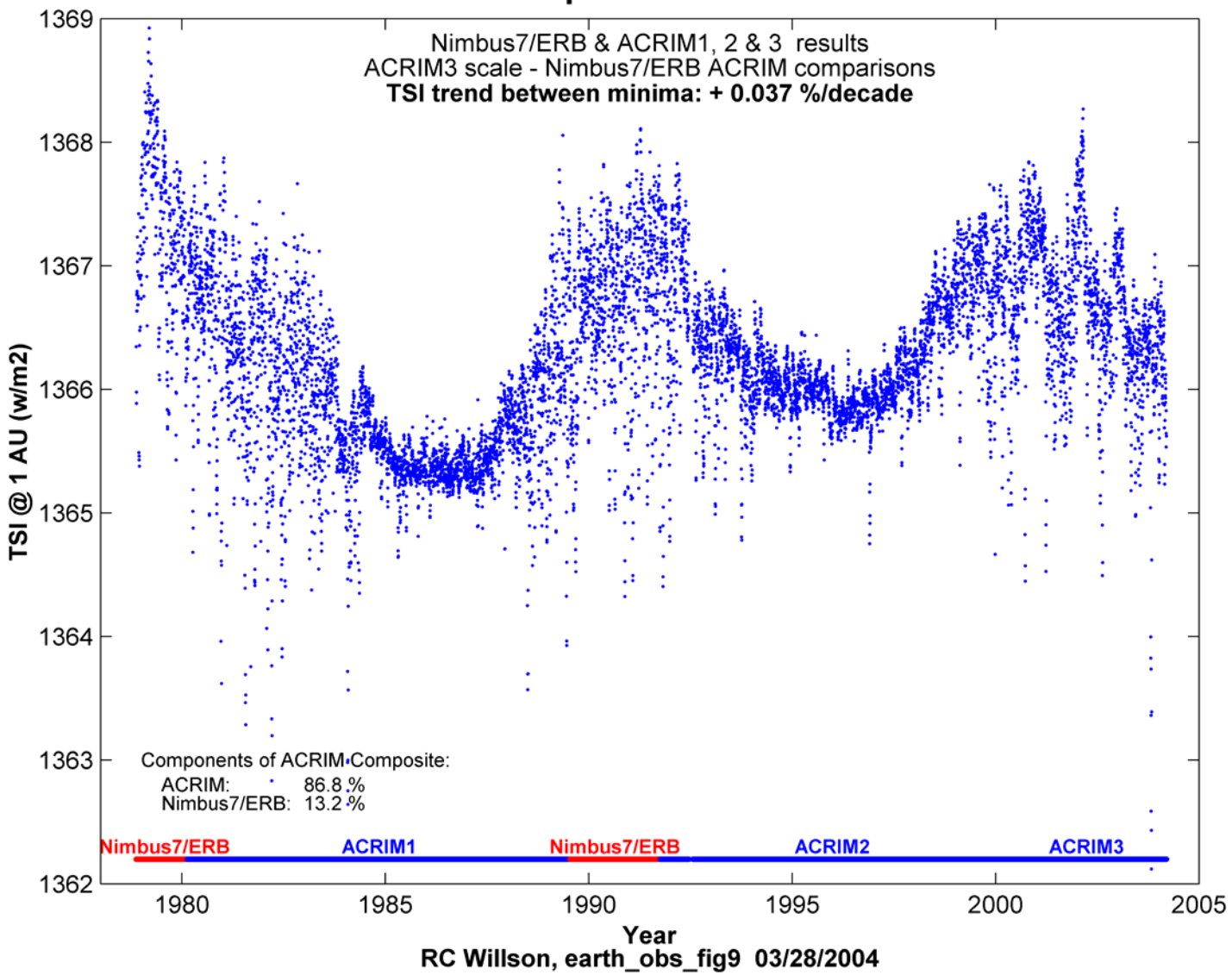
- **Uses**

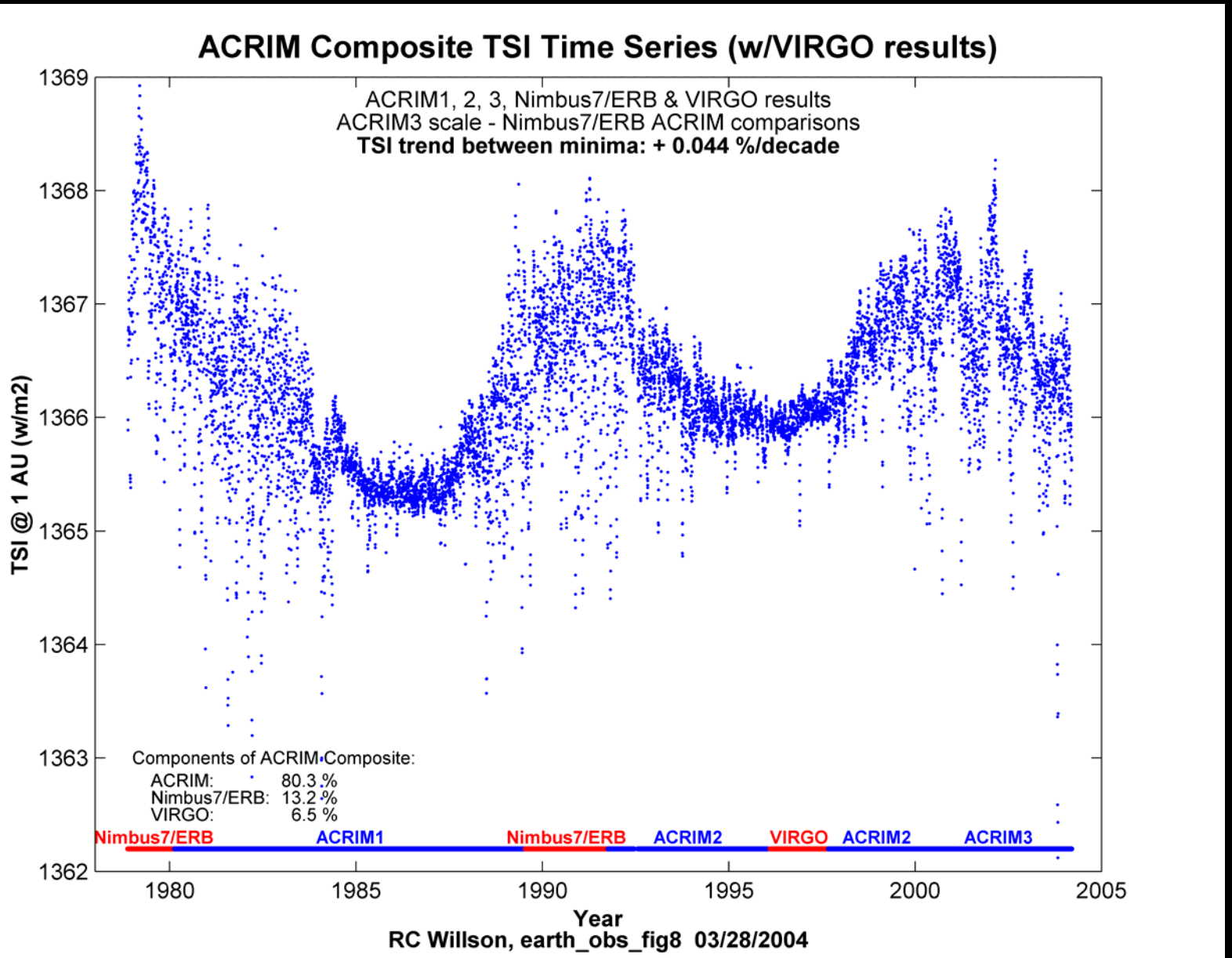
  Original published results from TSI experiments

  Overlapping comparisons to relate experiments at mutual precision level

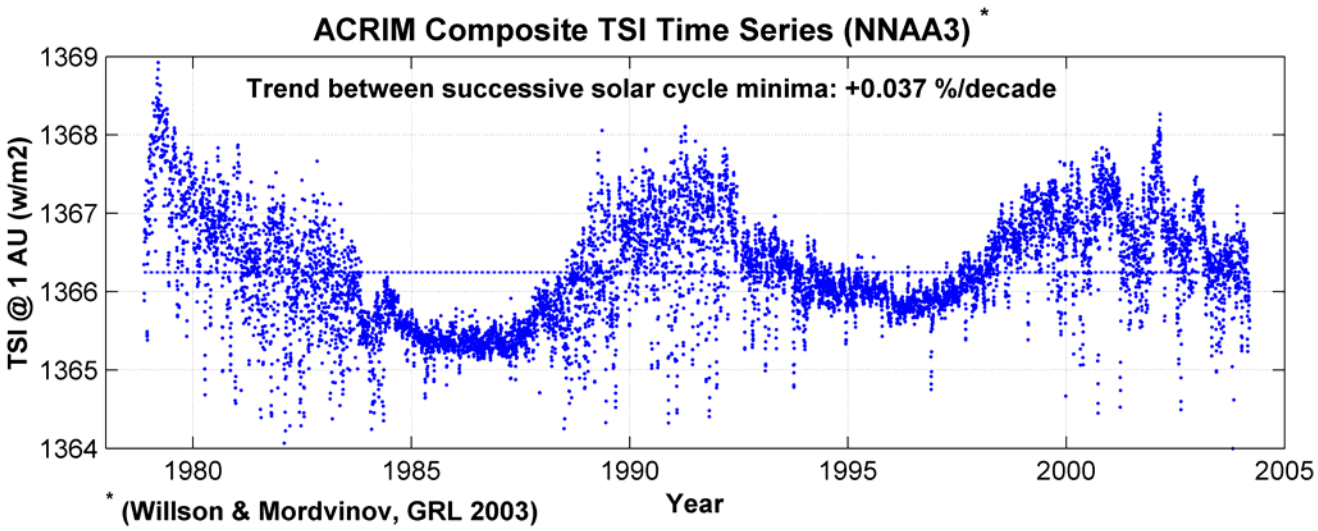
  ACRIM 1 & 2 comparisons with Nimbus7/ERB to bridge the ACRIM ‘gap’

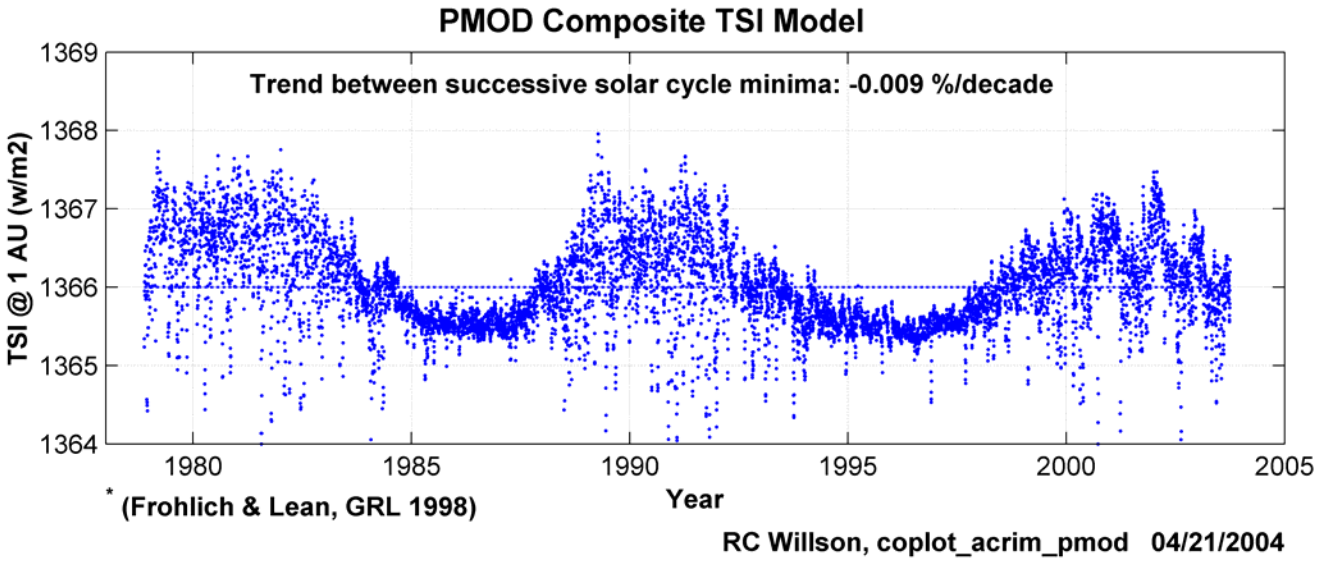
- **Reconciles Composite time series to ACRIM3 ‘native scale’**


ACRIM Composite TSI Time Series
Nimbus7/ERB & ACRIM1, 2 & 3 results
ACRIM3 scale - Nimbus7/ERB ACRIM comparisons
TSI trend between minima: + 0.037 %/decade
TSI @ 1 AU (w/m2)
1369
1368
1367
1366
1365
1364
1363
1362
1980
1985
1990
1995
2000
2005
Year
Components of ACRIM Composite:
ACRIM: 86.8 %
Nimbus7/ERB: 13.2 %
Nimbus7/ERB
ACRIM1
Nimbus7/ERB
ACRIM2
ACRIM3
RC Willson, earth_obs_fig9 03/28/2004


ACRIM Composite TSI Time Series (w/VIRGO results)
ACRIM1, 2, 3, Nimbus7/ERB & VIRGO results
ACRIM3 scale - Nimbus7/ERB ACRIM comparisons
TSI trend between minima: + 0.044 %/decade
TSI @ 1 AU (w/m2)
1369
1368
1367
1366
1365
1364
1363
1362
1980
1985
1990
1995
2000
2005
Year
Components of ACRIM Composite:
ACRIM: 80.3 %
Nimbus7/ERB: 13.2 %
VIRGO: 6.5 %
Nimbus7/ERB
ACRIM1
Nimbus7/ERB
ACRIM2
VIRGO
ACRIM2
ACRIM3
RC Willson, earth_obs_fig8 03/28/2004

Comparison of ACRIM and PMOD Composite TSI





Comparison of Composite TSI Approaches

- **ACRIM Composite TSI**

  Uses original published results from TSI experiments

  Uses results from Nimbus7/ERB, ACRIM 1,2 & 3 experiments

  Uses Nimbus7/ERB ACRIM 'gap' ratio to link ACRIM1 and ACRIM2

  Normalizes to ACRIM3 scale

- **PMOD Composite TSI**

  Modifies published results from TSI experiments

  Modifications justified by predictions of TSI proxy models

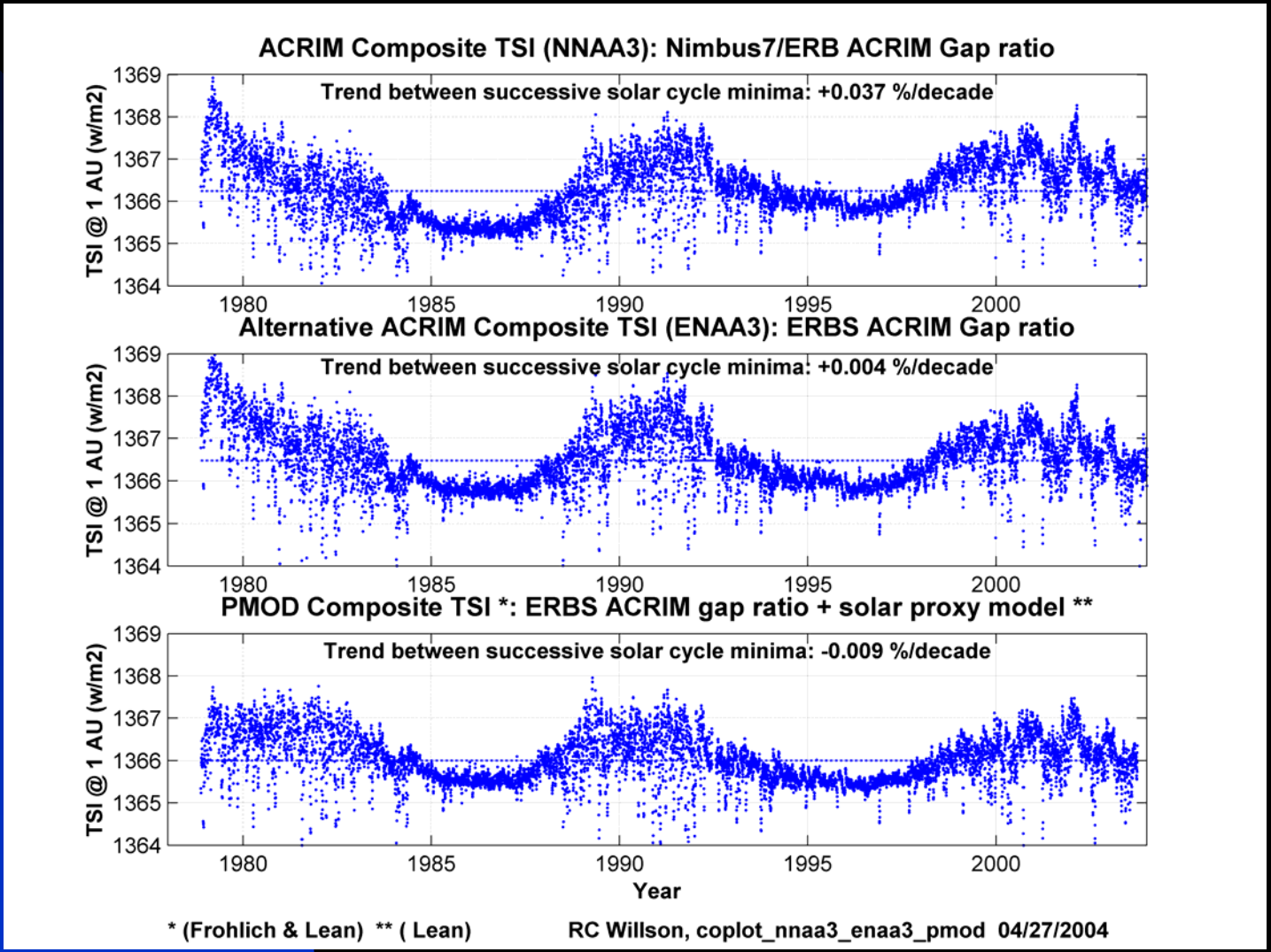
  Modifications not based on algorithm improvements/reprocessing

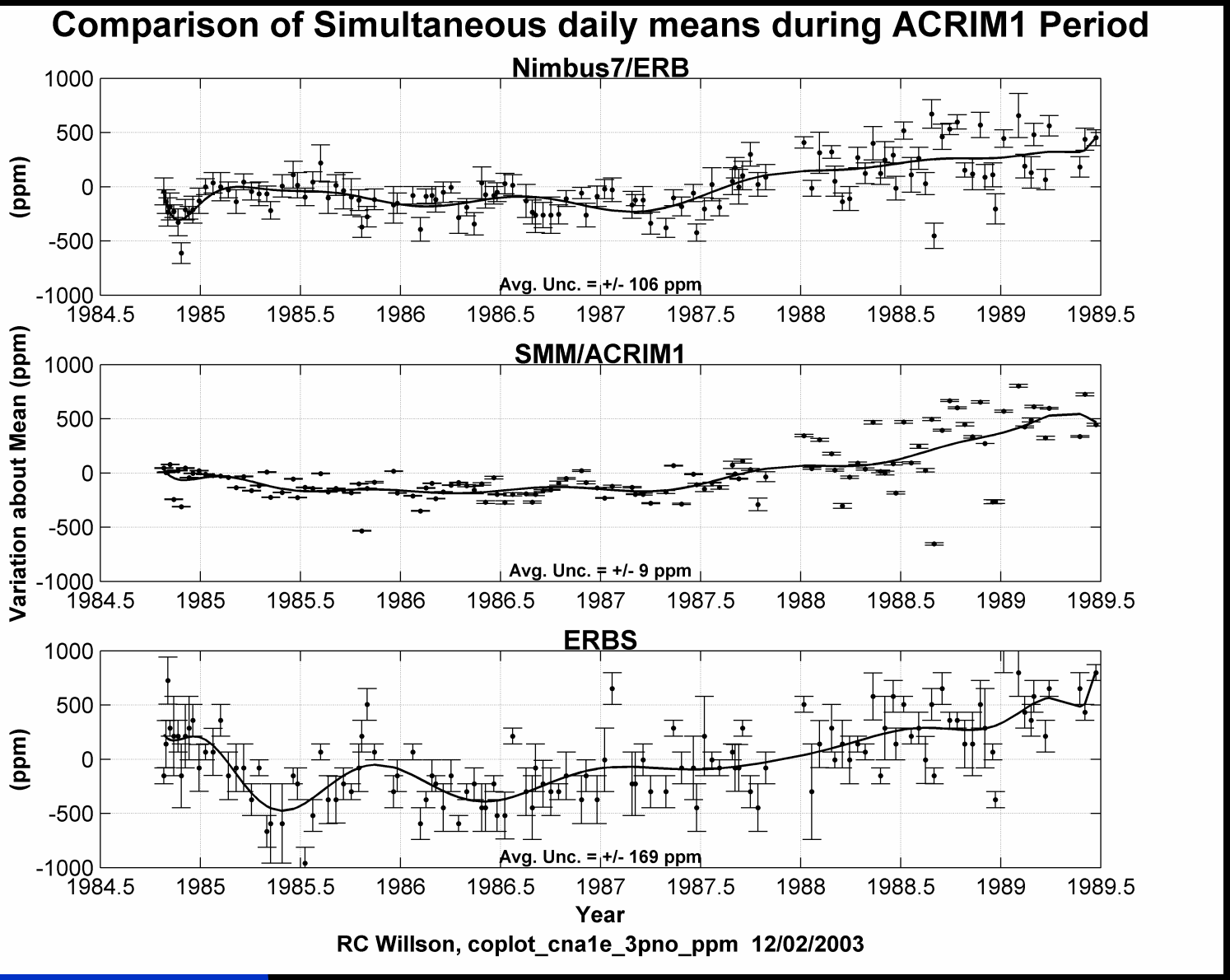
  Uses results from Nimbus7/ERB, ACRIM 1,2 & VIRGO experiments

  Uses ERBS ACRIM 'gap' ratio to link ACRIM1 and ACRIM2

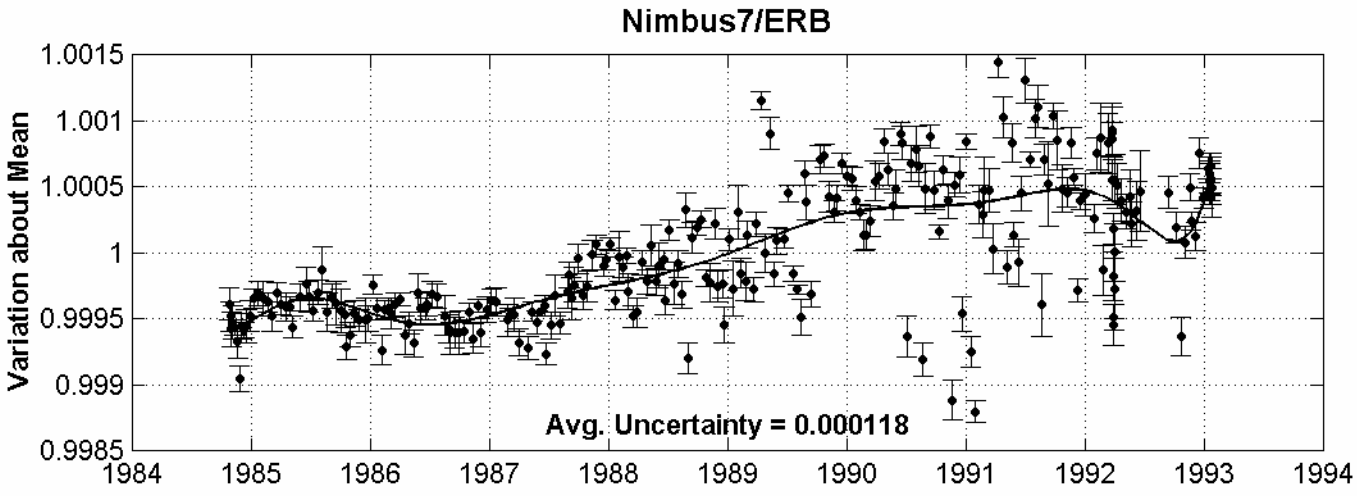
  Normalizes to VIRGO scale

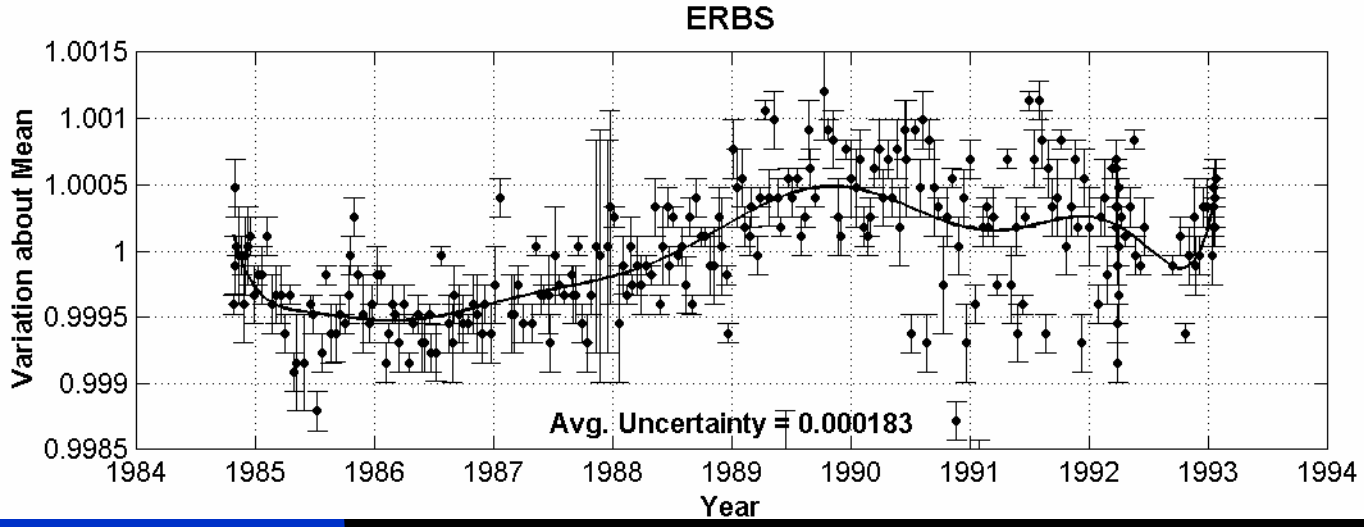
Composite TSI Dilemma: Use Nimbus7/ERB or ERBS ACRIM 'gap' ratio ?



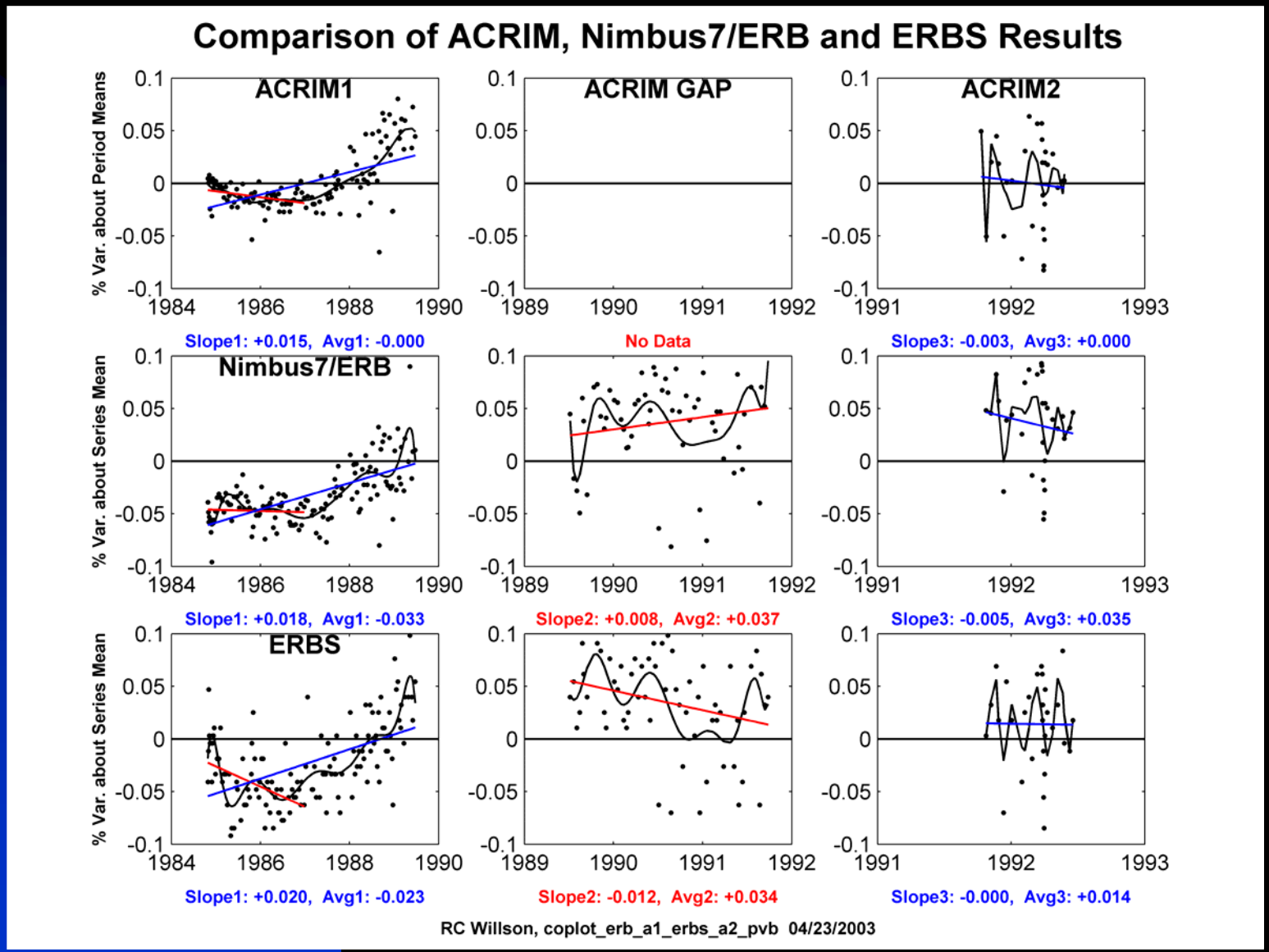

Comparison of Simultaneous daily means during ACRIM1 Period
Nimbus7/ERB
Avg. Unc. = +/- 106 ppm
SMM/ACRIM1
Avg. Unc. = +/- 9 ppm
ERBS
Avg. Unc. = +/- 169 ppm
(ppm)
Variation about Mean (ppm)
1000
500
0
-500
-1000
1984.5
1985
1985.5
1986
1986.5
1987
1987.5
1988
1988.5
1989
1989.5
Year
RC Willson, coplot_cna1e_3pno_ppm 12/02/2003

Comparison of Nimbus7/ERB and ERBS results
(Simultaneous Daily Means)





Comparison of Overlapping Observations during ACRIM1, ACRIM 'gap' and ACRIM2 Periods



Composite TSI Summary and Conclusions

- **ACRIM ‘gap’ test: proportionality of TSI and rising solar magnetic activity**

  Nimbus7/ERB *upward trend is compatible*

  ERBS *downward trend is incompatible* - caused by sensor degradation

- **ERBS degradation during ACRIM ‘gap’ equals ACRIM - PMOD trend difference**

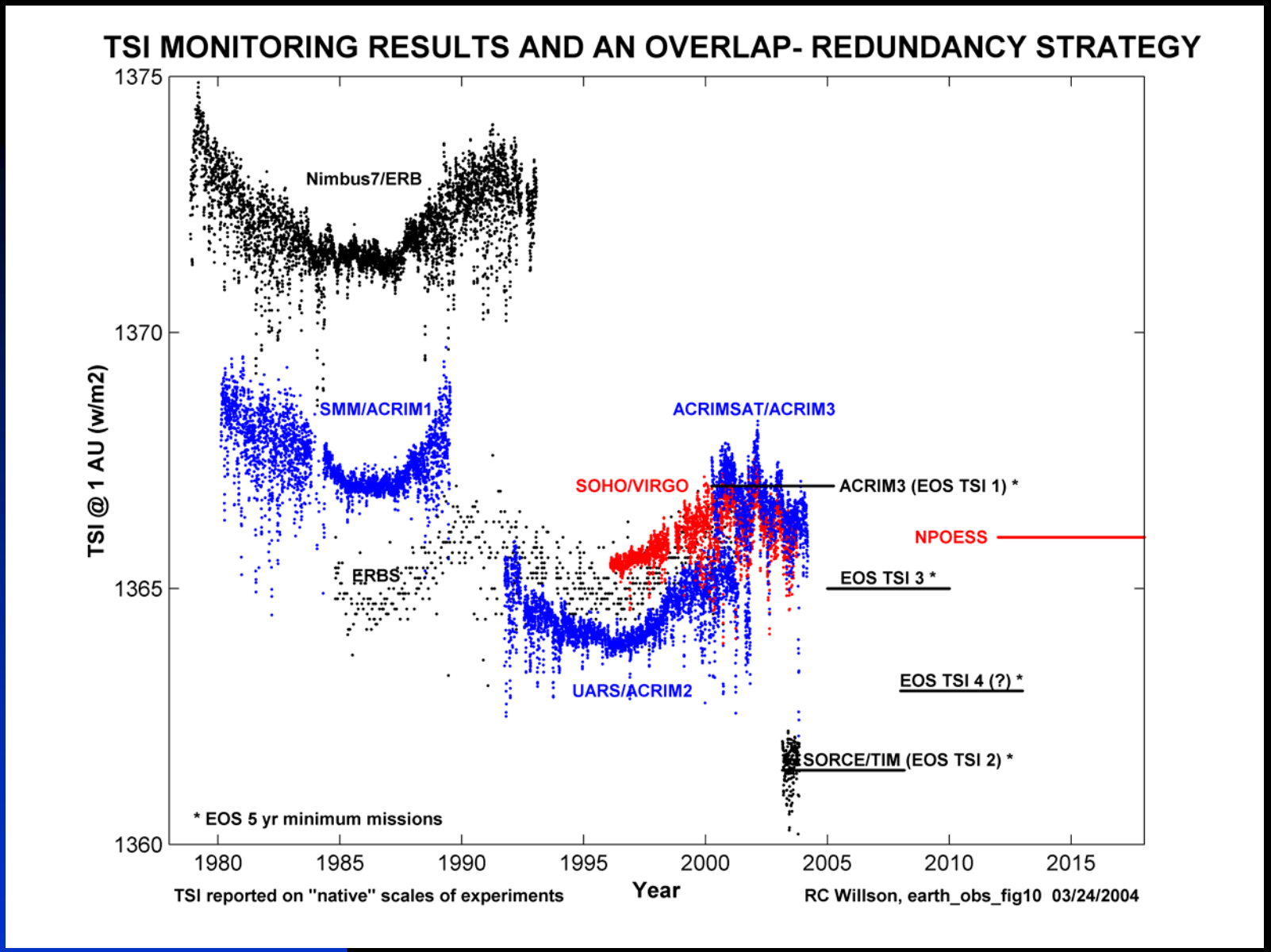
- **The absence of a minimum-to-minimum trend in composite models using ERBS results to bridge the ACRIM ‘gap’ is an artifact of ERBS degradation**

Quality of Extant TSI Database

- **Traceability from 1978 to present provided by *overlap strategy*: ~ 100 ppm**
- **Traceability achievable by current instrumentation: ~ 5 ppm/yr**
- **SI uncertainty achieved by satellite instrumentation to date: ~ 1000 ppm**
- **SI uncertainty required for paradigm change in observational strategy: 100 ppm**
- **Realization of 100 ppm SI uncertainty to date: lab sensors at LHe temperatures**

A Strategy for TSI Database Continuity

- **Redundant, overlaping observations yield maximum traceability with current technology**
- **Redundant experiments required to prevent a single point failure in the Overlap Strategy**
- **TSI operational monitoring begins on NPOESS ~ 2012**
- **Two additional EOS TSI experiments required to bridge SORCE/TIM – NPOESS gap**


TSI MONITORING RESULTS AND AN OVERLAP- REDUNDANCY STRATEGY
TSI @ 1 AU (w/m2)
1375
1370
1365
1360
1980
1985
1990
1995
2000
2005
2010
2015
Year
Nimbus7/ERB
SMM/ACRIM1
ACRIMSAT/ACRIM3
SOHO/VIRGO
ACRIM3 (EOS TSI 1) *
NPOESS
ERBS
EOS TSI 3 *
UARS/ACRIM2
EOS TSI 4 (?) *
SORCE/TIM (EOS TSI 2) *
* EOS 5 yr minimum missions
TSI reported on "native" scales of experiments
RC Willson, earth_obs_fig10 03/24/2004