Jason-1 orbit determination with DORIS and SLR: An alternative approach for accommodating the SAA effect

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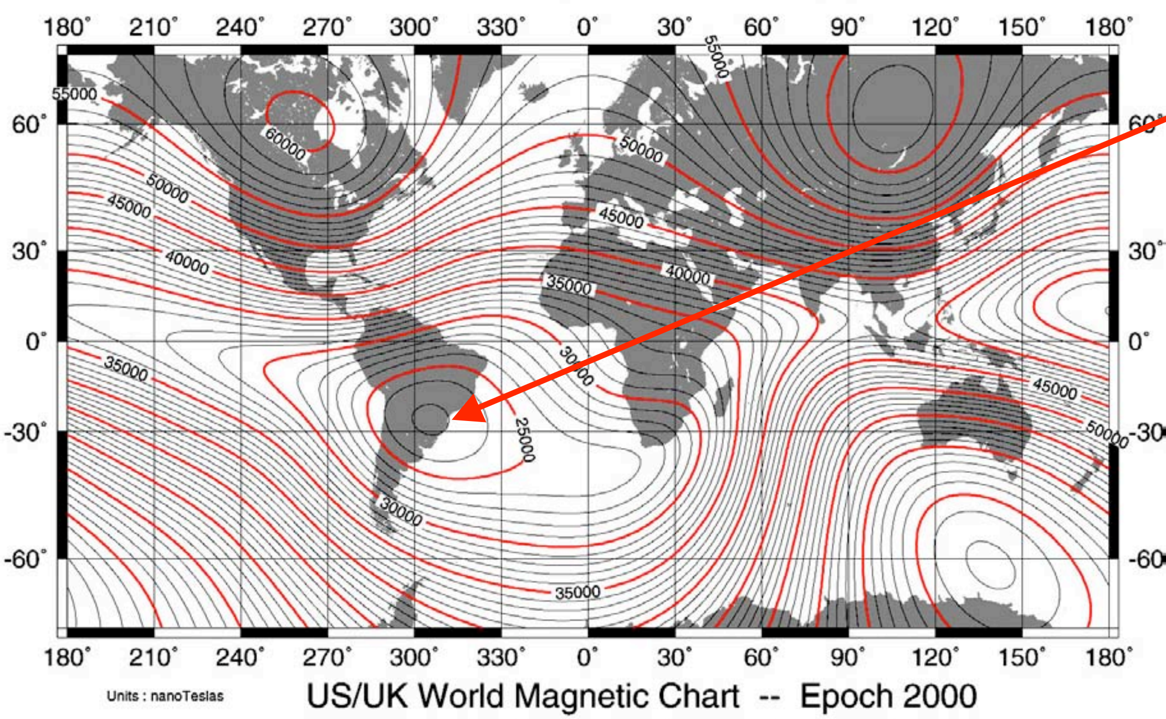
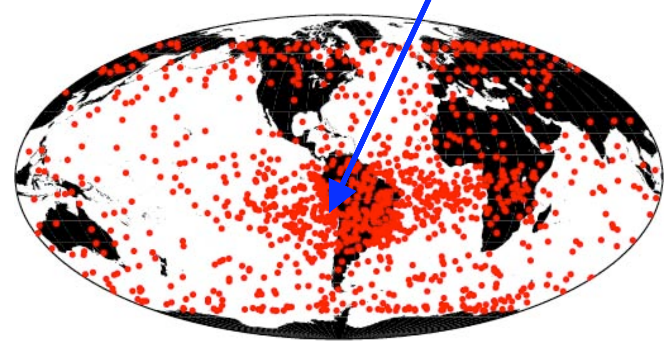
SAA Effect on Jason-1

- It is clear that the oscillator on Jason-1 experiences rapid frequency changes during exposure to the increased radiation environment of the SAAΩ
  - Serious effect on station positioning which is becoming progressively worse
  - Strategies to accommodate this being investigated
  - Effect on POD appears to be less serious, so far



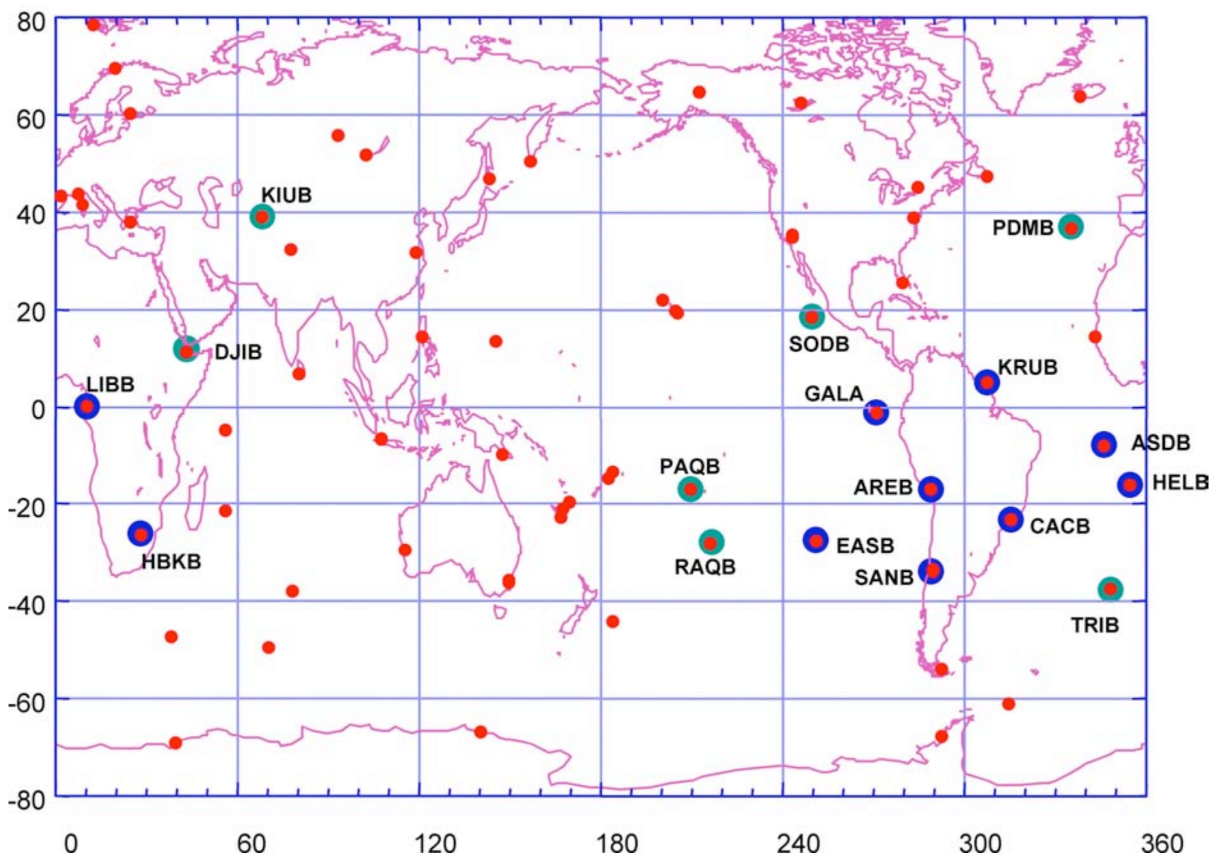
US/UK World Magnetic Chart -- Epoch 2000
Total Intensity - Main Field (F)

The South Atlantic Anomaly is an area of low magnetic field and captured disturbance particles that can cause various electronic upsets



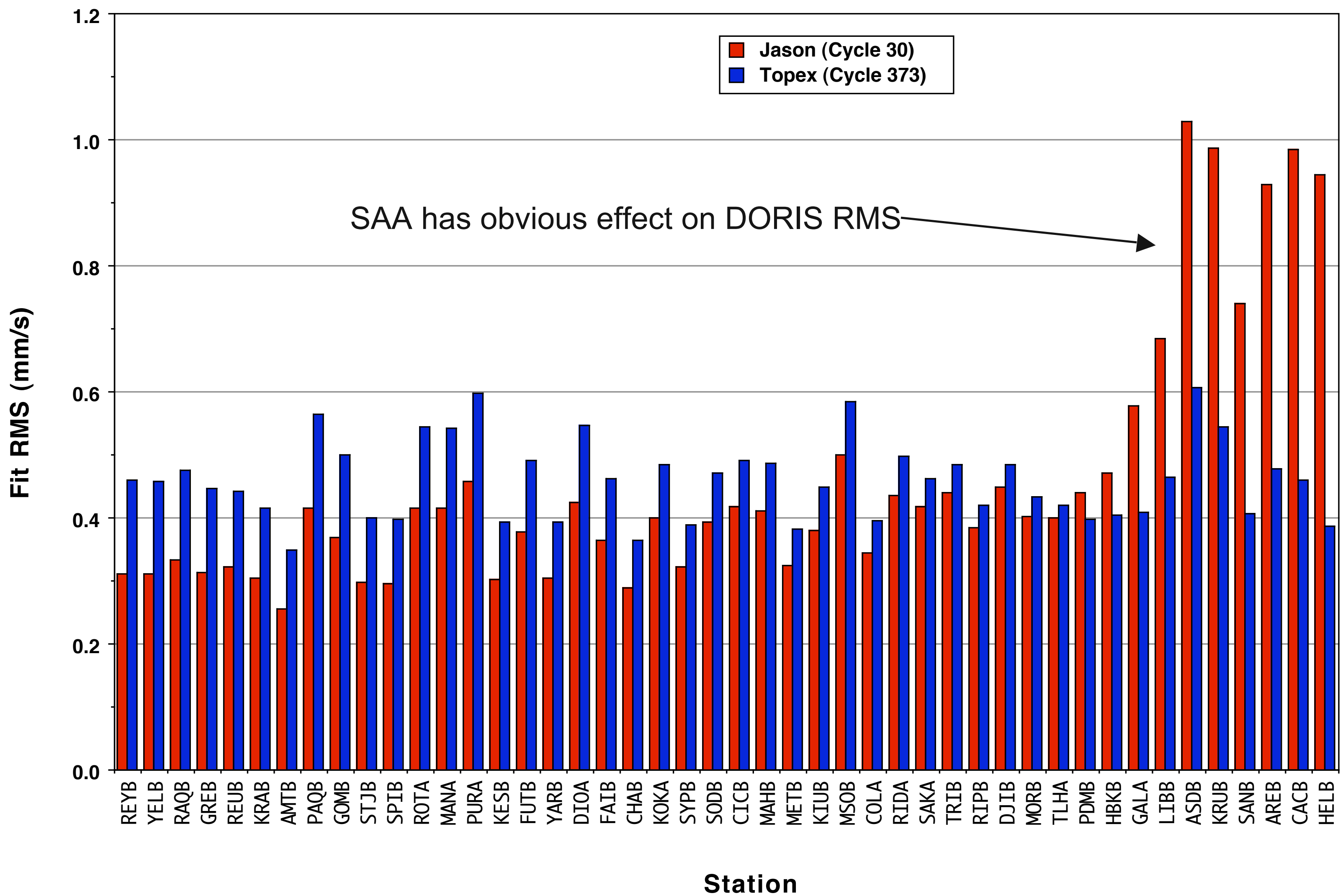
Jason-1 Blackjack GPS Receiver Resets

Stations Affected by SAA



Is the SAA impacting POD accuracy in the long term as the effect increases with time?

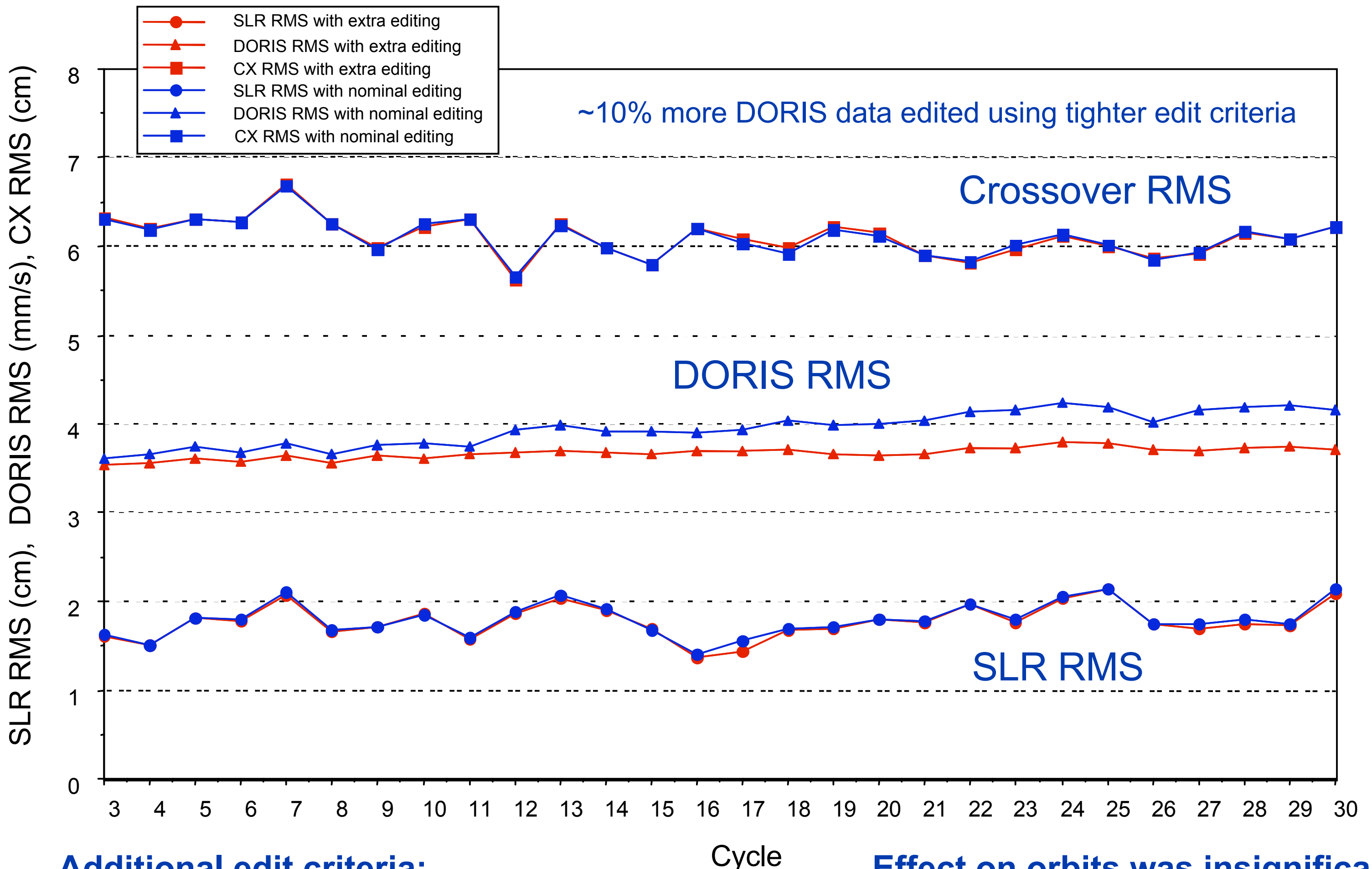
DORIS on Jason-1 and T/P



Try Tighter Editing

- Using ‘Guier Plane’ analysis on post-fit residuals, it possible to infer the apparent orbit error along two orthogonal directions: along-track and slant-range (similar to bias and time-bias for SLR)
  - Minimal sensitivity to out-of-plane (cross-track) orbit error; ignored
  - This ‘navigation solution’ will reflect orbit errors and station coordinate errors, but generally to be dominated by orbit errors
  - The residual frequency offset and troposphere are also estimated
- Passes with large SAA effect have large ‘navigation’ errors
- Typical editing removes weak, low-elevation passes, passes with large gaps or passes with excess noise, tossing ~9% of the data
  - Tolerance on navigation solutions is quite loose
- Tight editing on navigation solutions (30 cm, 2.5% troposphere) leads to the additional loss of another 15% or more of the data
  - Nearly all data from SAA stations is caught and removed
  - Some weaker passes from other sites are also ‘caught in the net’

Earlier Results



Additional edit criteria:
Pass RMS < 0.6 mm/s
slant and tangential navigation errors < 50 cm
troposphere errors < 4%

Effect on orbits was insignificant
Radial rms < 3 mm
X,Y,Z shifts < 2 mm
Crossover RMS and mean essentially unchanged

Effect of SSA on Station Navigation Errors

Cycle 3 (RMS=0.35 mm/s)

station	# pass	east	std	north	std	ht	std
ADEA	47	2	1	-1	1	0	1
AMTB	26	-4	2	-2	1	-1	1
AREB	12	2	2	6	2	-12	2
ASDB	4	-6	9	-4	6	-13	3
BADA	52	1	1	-1	1	1	1
CACB	6	-4	4	-19	3	-9	4
CHAB	29	4	1	-1	2	1	1
CICB	14	1	1	4	2	-2	1
COLA	16	2	3	3	2	2	1
DIOA	18	-2	3	-3	2	5	2
DJIB	25	0	2	3	2	1	1
EASB	23	-2	2	-1	2	3	2
EVEB	11	-4	3	1	1	7	2
FAIB	50	1	1	-2	1	3	1
FUTB	19	0	2	4	1	5	1
GOMB	33	1	1	3	1	1	1
GREB	32	1	1	1	1	2	1
HBKB	29	-3	1	-8	1	1	1
HELB	15	3	2	-14	2	-4	2
KESB	30	-2	1	-1	2	-1	1
KIUB	32	-3	2	-3	1	1	1
KOKA	30	0	1	3	1	-2	1
KRAB	30	2	1	-1	1	0	1
KRUB	15	2	1	10	2	-1	1
LIBB	14	-4	2	6	3	-4	1
MAHB	20	1	2	3	1	2	1
MANA	27	2	2	-1	2	-1	1
MARB	41	0	1	-4	1	2	1
METB	39	1	1	1	1	0	1
MORA	20	0	1	-3	2	-1	1
MSOB	22	-6	3	-3	3	0	1
PAQB	20	1	2	2	1	1	1
PDMB	18	2	2	-5	3	3	2
RAQB	18	-1	2	1	1	-4	1
REUB	1	0	0	1	0	-11	0
REYB	11	-2	1	0	1	3	1
RIPB	48	-1	1	-1	1	3	1
ROTA	43	0	1	-2	1	3	1
SANB	20	1	1	-11	2	-3	2
SODB	25	1	2	5	1	3	1
STJB	37	-1	1	-2	1	-1	1
SYPB	34	-1	1	0	1	0	1
TLHA	30	1	1	2	1	0	1
YARB	31	0	1	-2	1	-1	1
YELB	49	0	3	-3	3	-2	1

units are cm

Cycle 63 (RMS=0.45 mm/s)

station	# pass	east	std	north	std	ht	std
ASDB	2	32	10	-36	1	-98	3
CHAB	61	4	2	-2	1	2	1
CICB	34	1	2	4	2	3	1
COLA	28	7	2	1	3	6	1
DJIB	31	-2	2	14	3	8	2
EASB	24	-11	6	-40	4	-22	5
EVEB	21	-1	2	0	2	6	1
FAIB	62	1	1	1	1	4	1
FUTB	31	-2	3	-4	2	7	1
GREB	35	1	3	-3	3	9	2
HBKB	29	-6	5	-22	3	18	2
KESB	36	4	3	-8	2	4	2
KIUB	40	-2	2	2	2	5	1
KOLB	37	2	2	17	2	4	1
KRAB	63	4	1	0	1	3	1
KRUB	11	-18	15	69	6	32	11
LIBB	13	-14	9	41	6	-44	6
MAHB	16	15	4	7	4	1	3
MARB	59	-2	2	-9	2	8	1
METB	9	8	2	-2	3	7	2
PAQB	31	-4	2	-11	3	3	1
PDMB	17	-11	4	-6	3	5	2
RAQB	30	0	1	-10	2	4	1
REUB	34	7	4	-9	3	1	3
REYB	12	0	3	1	3	-2	2
RIDA	32	9	6	-15	4	16	3
RIPB	59	1	4	-1	3	18	2
ROTA	55	8	3	8	3	9	1
SALB	20	-7	5	28	5	12	6
SANB	6	-23	8	-53	16	24	5
SODB	30	3	5	17	2	14	2
SPJB	24	9	2	-6	3	4	1
STJB	1	2	0	-9	0	4	0
SYPB	54	-2	1	5	1	8	1
THUB	31	2	1	-2	1	2	1
TLHA	20	-10	4	1	3	4	2
TRIB	33	-19	6	-6	3	18	3
YARB	40	5	1	-1	2	1	1
YELB	61	3	1	-2	1	6	1

The worst is not represented here; some stations not even passing CNES editing

INTERNATIONAL DORIS SERVICE

IDS

Effect of Editing on Navigation Errors

CSR

Cycle 63 Nominal Editing (RMS = 0.45 mm/s)

station	# pass	east	std	north	std	ht	std
ASDB	2	32	10	-36	1	-98	3
CHAB	61	4	2	-2	1	2	1
CICB	34	1	2	4	2	3	1
COLA	28	7	2	1	3	6	1
DJIB	31	-2	2	14	3	8	2
EASB	24	-11	6	-40	4	-22	5
EVEB	21	-1	2	0	2	6	1
FAIB	62	1	1	1	1	4	1
FUTB	31	-2	3	-4	2	7	1
GREB	35	1	3	-3	3	9	2
HBKB	29	-6	5	-22	3	18	2
KESB	36	4	3	-8	2	4	2
KIUB	40	-2	2	2	2	5	1
KOLB	37	2	2	17	2	4	1
KRAB	63	4	1	0	1	3	1
KRUB	11	-18	15	69	6	32	11
LIBB	13	-14	9	41	6	-44	6
MAHB	16	15	4	7	4	1	3
MARB	59	-2	2	-9	2	8	1
METB	9	8	2	-2	3	7	2
PAQB	31	-4	2	-11	3	3	1
PDMB	17	-11	4	-6	3	5	2
RAQB	30	0	1	-10	2	4	1
REUB	34	7	4	-9	3	1	3
REYB	12	0	3	1	3	-2	2
RIDA	32	9	6	-15	4	16	3
RIPB	59	1	4	-1	3	18	2
ROTA	55	8	3	8	3	9	1
SALB	20	-7	5	28	5	12	6
SANB	6	-23	8	-53	16	24	5
SODB	30	3	5	17	2	14	2
SPJB	24	9	2	-6	3	4	1
STJB	1	2	0	-9	0	4	0
SYPB	54	-2	1	5	1	8	1
THUB	31	2	1	-2	1	2	1
TLHA	20	-10	4	1	3	4	2
TRIB	33	-19	6	-6	3	18	3
YARB	40	5	1	-1	2	1	1
YELB	61	3	1	-2	1	6	1

units are cm

Cycle 63 Tight Editing (RMS = 0.36 mm/s)

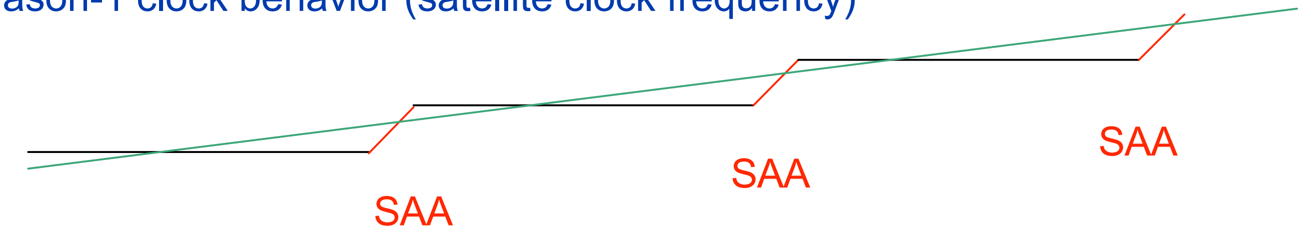
station	# pass	east	std	north	std	ht	std
CHAB	45	4	1	-1	1	2	1
CICB	23	1	1	4	2	2	1
COLA	25	4	2	1	2	5	1
DJIB	19	3	2	7	3	8	2
EVEB	9	2	2	3	3	6	1
FAIB	58	1	1	0	1	4	1
FUTB	26	1	1	-3	2	6	1
GREB	28	0	1	0	2	8	1
KESB	27	7	2	-7	2	6	2
KIUB	32	-3	2	0	1	5	1
KOLB	27	2	2	13	2	5	1
KRAB	58	4	1	0	1	3	1
MAHB	13	7	1	4	2	3	3
MARB	48	0	1	-6	1	8	1
METB	6	12	2	-2	4	9	2
PAQB	23	-2	1	-10	2	3	1
PDMB	12	-4	2	-6	3	4	3
RAQB	26	0	1	-8	2	4	1
REUB	20	3	2	1	3	3	2
REYB	3	8	6	-8	3	-1	4
RIDA	21	-8	2	-4	2	9	3
RIPB	45	-6	1	-7	1	10	1
ROTA	34	0	1	3	1	6	1
SODB	21	-1	3	14	1	12	2
SPJB	12	14	2	-7	4	7	1
SYPB	45	-1	1	5	1	9	1
THUB	20	2	2	-5	1	3	1
TLHA	15	-7	3	-1	3	5	2
TRIB	12	0	2	-4	2	9	2
YARB	34	4	1	-1	2	1	1
YELB	56	2	1	-2	1	6	1

Up to 30% of the data is removed using tight editing on station navigation solutions

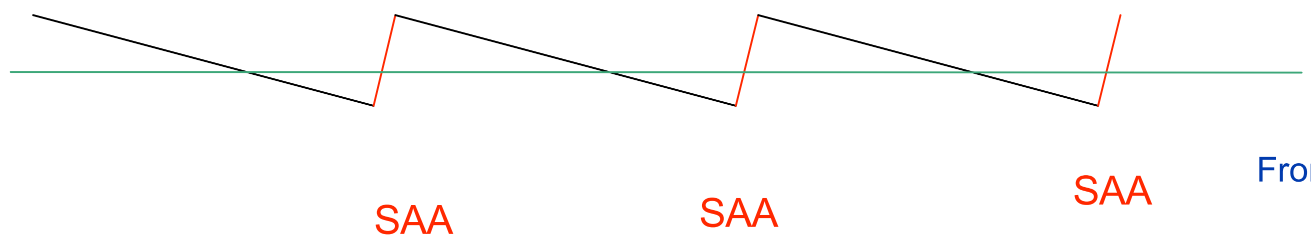
Systematic height bias remains due to effect of frequency drift model, which must accommodate both SAA and non-SAA drifts

Indirect Effect of SAA on 'non-SAA' Data

Actual Jason-1 clock behavior (satellite clock frequency)



Jason-1 satellite clock in DORIS data (after removal of a long-term polynomial by CNES)



From P. Willis

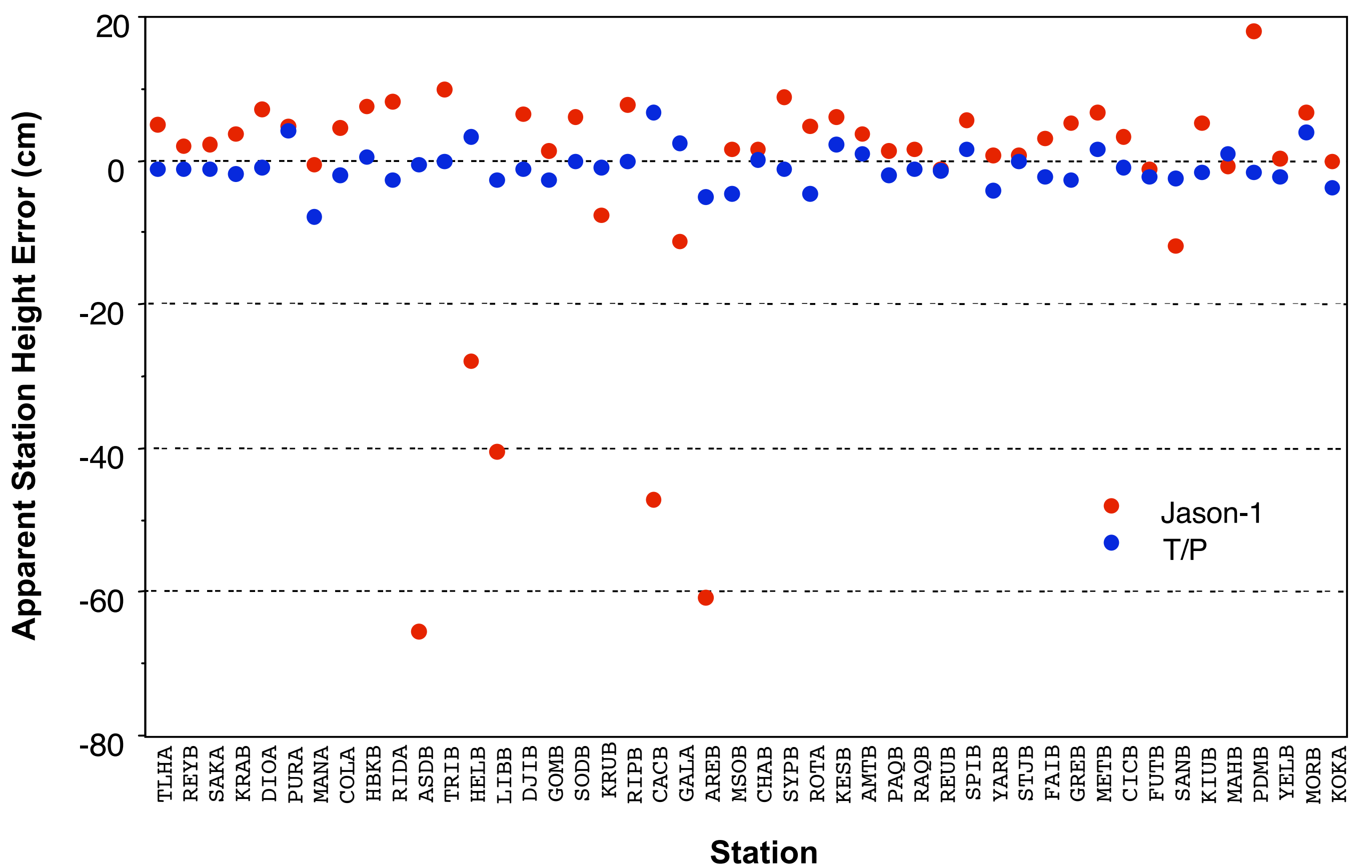
When the SAA effect was smaller, the impact on 'non-SAA' data was negligible

As SAA effect increases, however, the induced slope on 'non-SAA' data becomes a problem

Can problem for non-SAA stations be addressed with a global bias-drift parameter?
(effect is not station dependent; it is common to all non-SAA stations through clock model)

Geodetic Consequences

- There is a systematic error in the frequency model used to scale phase to range that is the result of the SAA effect, which is affecting all DORIS data from Jason-1
  - All stations outside of affected area have height errors which are biased in the opposite sense of the affected stations



Effect of Global Bias-Drift Parameter

units are cm

Cycle 63 Tight Editing Only
(RMS = 0.36 mm/s)

station	# pass	east	std	north	std	ht	std
CHAB	45	4	1	-1	1	2	1
CICB	23	1	1	4	2	2	1
COLA	25	4	2	1	2	5	1
DJIB	19	3	2	7	3	8	2
EVEB	9	2	2	3	3	6	1
FAIB	58	1	1	0	1	4	1
FUTB	26	1	1	-3	2	6	1
GREB	28	0	1	0	2	8	1
KESB	27	7	2	-7	2	6	2
KIUB	32	-3	2	0	1	5	1
KOLB	27	2	2	13	2	5	1
KRAB	58	4	1	0	1	3	1
MAHB	13	7	1	4	2	3	3
MARB	48	0	1	-6	1	8	1
METB	6	12	2	-2	4	9	2
PAQB	23	-2	1	-10	2	3	1
PDMB	12	-4	2	-6	3	4	3
RAQB	26	0	1	-8	2	4	1
REUB	20	3	2	1	3	3	2
REYB	3	8	6	-8	3	-1	4
RIDA	21	-8	2	-4	2	9	3
RIPB	45	-6	1	-7	1	10	1
ROTA	34	0	1	3	1	6	1
SODB	21	-1	3	14	1	12	2
SPJB	12	14	2	-7	4	7	1
SYPB	45	-1	1	5	1	9	1
THUB	20	2	2	-5	1	3	1
TLHA	15	-7	3	-1	3	5	2
TRIB	12	0	2	-4	2	9	2
YARB	34	4	1	-1	2	1	1
YELB	56	2	1	-2	1	6	1
Average		2		-1		5	

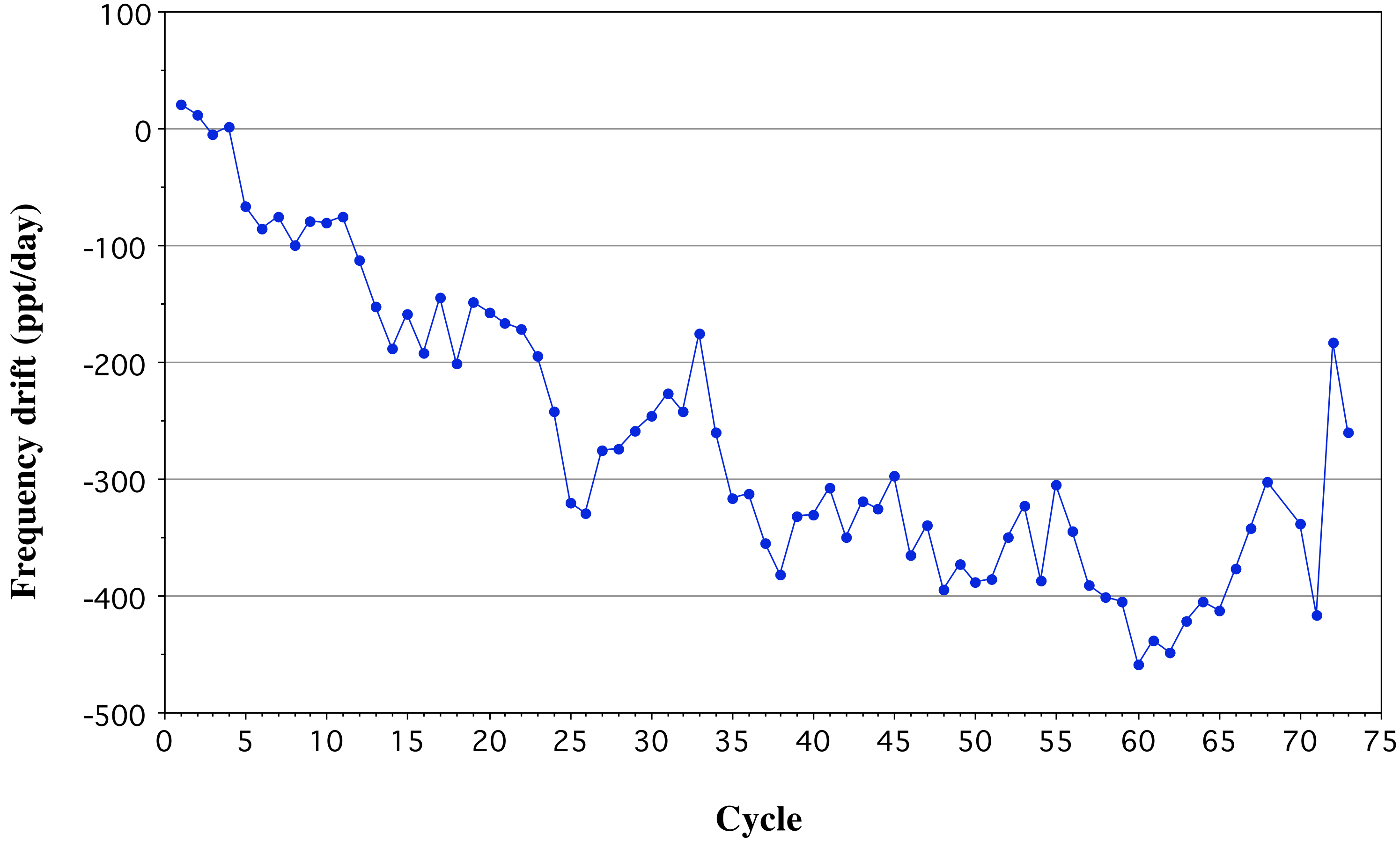
Cycle 63 Tight Editing and Global Drift
(RMS=0.35 mm/s)

station	# pass	east	std	north	std	ht	std
CHAB	45	4	1	2	1	-3	1
CICB	23	0	1	3	1	-3	1
COLA	25	2	1	2	2	0	1
DJIB	23	-2	2	10	3	4	2
EVEB	10	3	1	2	2	2	1
FAIB	58	0	1	2	1	-2	1
FUTB	26	0	1	-3	2	0	1
GREB	27	0	1	-3	2	3	1
KESB	27	2	2	-5	2	2	1
KIUB	33	-1	1	1	1	0	1
KOLB	27	2	2	11	1	0	1
KRAB	58	1	1	-2	1	-2	1
MAHB	12	5	2	2	3	0	3
MARB	49	-1	1	-3	1	3	1
METB	6	3	2	-2	4	3	2
PAQB	23	-2	1	-10	2	-3	1
PDMB	12	-1	2	-6	3	-1	2
RAQB	26	-1	1	-6	2	-1	1
REUB	22	-1	1	-3	3	0	2
REYB	2	10	5	-3	4	-4	3
RIDA	22	-6	2	-6	2	5	3
RIPB	45	-6	1	-4	1	4	1
ROTA	36	-1	1	2	1	1	1
SODB	22	-4	2	13	1	8	2
SPJB	13	6	2	-3	4	3	2
SYPB	48	-3	1	2	1	4	1
THUB	20	-3	2	1	2	-1	1
TLHA	14	-6	3	0	3	0	2
TRIB	12	-4	2	-2	2	4	2
YARB	32	3	1	-1	1	-4	1
YELB	56	2	1	-1	1	0	1
Average		0		0		1	

Bias in all 3 components has been reduced or removed through a single extra parameter

Note: bias-drift parameter CANNOT be used if data affected by SAA are not edited

Bias-drift vs Time



Impact on POD

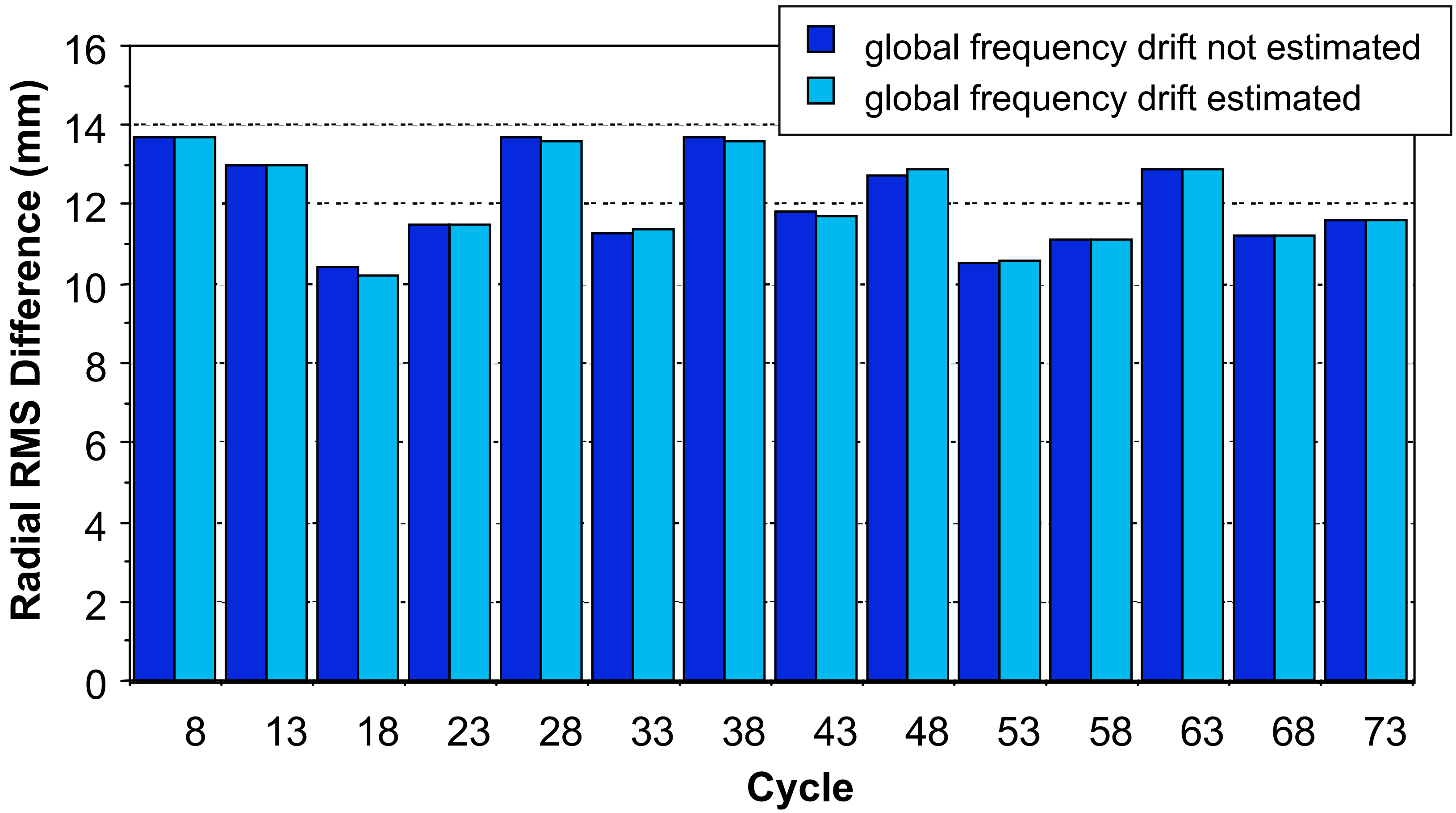
- In spite of strong SAA effect on fits, POD is only slightly affected (in the case of these 10-day dynamic orbits; reduced-dynamics will be much more affected)
  - Strong editing of affected stations provides only modest orbit improvement
  - Adding a global bias-drift parameter has an insignificant effect on orbit quality
    - Removes systematic error in residuals that looks like station height error (leading to slightly better fits)
    - High correlation (0.8) with station height estimation; cannot be used for positioning

CASE (Cycles 68, 73)	SLR RMS (mm)	DORIS RMS (mm/s)	CX RMS/Mean (mm)	Z-shift (mm)	Radial RMS diff (mm)
Normal edit, no bias-drift	14.9 16.4	0.430 (72213 obs) 0.485 (78642 obs)	58.1 / 6.9 60.4 / 0.7	+8 -9	11.4 11.9
Strong edit, no bias-drift	14.5 15.5	0.347 (55536 obs) 0.354 (55213 obs)	58.0 / 5.2 59.8 / 0.6	+8 -9	11.2 11.6
Strong edit, global bias-drift	14.4 15.4	0.342 (55536 obs) 0.351 (55213 obs)	58.0 / 5.0 59.8 / 0.4	+8 -9	11.2 11.6

(note: results based on using GGM01S; orbit comparisons relative to JPL GGM01S orbits from B. Haines)

Comparison with GPS Orbits

Average difference RMS identical at 12.1 mm with GGM01S (13.7 mm with JGM-3)



No discernable benefit from including bias-drift parameter for POD

Conclusions

- South Atlantic Anomaly has dramatic effects on data quality for stations in the vicinity
  - Geodetic applications (position/velocity estimation) severely affected for SAA sites
  - Indirect effect on remaining sites through clock model
    - Adding bias-drift parameter can absorb clock model error but is correlated with station heights (correlation coefficient of ~0.8)
- Impact on long-arc orbits is small
  - Some benefit seen with strong editing applied
  - Adding bias-drift parameter improves fits slightly but orbit accuracy not significantly improved

Additonal Notes: Troposphere Estimation

- Troposphere estimation is typically of the form

  $\square\ (H_{dry} + H_{wet})_Z\ f\,(\square)$ or $H_{dry} + \square\ H_{wet}\ f\,(\square)$

  where □ is the scale factor and f is the mapping function

- If pressure measurement is reliable, latter formulation may be more effective (GPS, PRARE)
  - *Q: Is meterological information from DORIS stations reliable? Are the equipment monitored or calibrated regularly?*

- Typically, no apriori constraint is applied to □
  - This is pessimistic...assumes no confidence in model
  - Early station estimation with DORIS for T/P showed considerably improvement in results using significant apriori constraint on troposphere parameter (few percent)

Additional Notes: Time Bias

- DORIS timing bias on T/P is currently 10-11 microsec; 5-6 microsec on Jason-1 (Envisat?)
- Time bias on SPOT satellites is an unknown
- May average N-S at any location but could have a non-zero E-W component (probably only significant for T/P)
- What is impact on positioning if time bias is not removed?