Reanalysis and extension of the ILRS weekly products

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Outline

- ILRS SLR and ITRF2005

- Sources of significant error in SLR

- ILRS analysis improvements (status)

- Implications for future ITRF

- Schedule of improved & extended products

- Future (additional) improvements

ILRS SLR in ITRF2005

- ITRF2005 was released in October 2006

- ITRF product based on a weekly set rather than single set of normal equations

- Includes many sites that were not present in ITRF2000 or poorly estimated

- Because of a significant scale difference between the SLR and VLBI, scale is defined by VLBI only
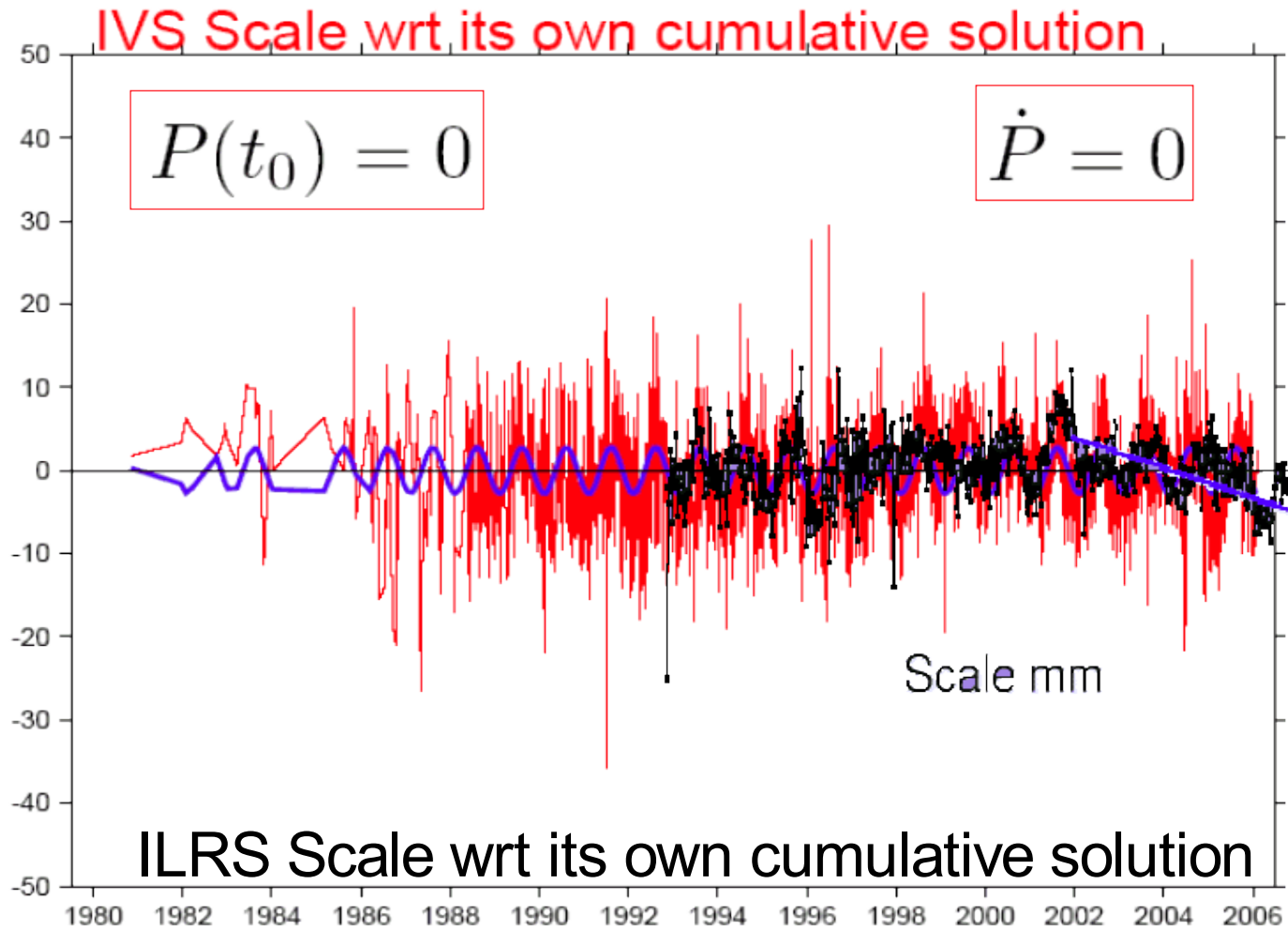
ITRF2005

RMS difference [mm] of the **ILRS Weekly products** vs. ITRF2000 and ITRF2005 (3 successive weeks)

Group RMS [mm]	ITRF2000	ITRF2005	ITRF2000	ITRF2005	ITRF2000	ITRF2005
	June 3, 2006		June 10, 2006		June 17, 2006	
All sites	40	**8**	36	**9**	32	**9.6**
Core sites (24) (16)	13	**7**	13	**8**	12	**8**

ITRF2005 - Scale Issue

- **SLR and VLBI scales (according to ITRS):**

IVS Scale wrt its own cumulative solution

$$P(t_0) = 0 \qquad \dot{P} = 0$$

Scale mm

ILRS Scale wrt its own cumulative solution

SLR / VLBI Scale from ITRS

SCALE

VLBI

SLR

σ_{SCALE}

$\sigma_{D_{VLBI}} \sim 3$ mm

$\sigma_{D_{SLR}} \sim 1.5$ mm
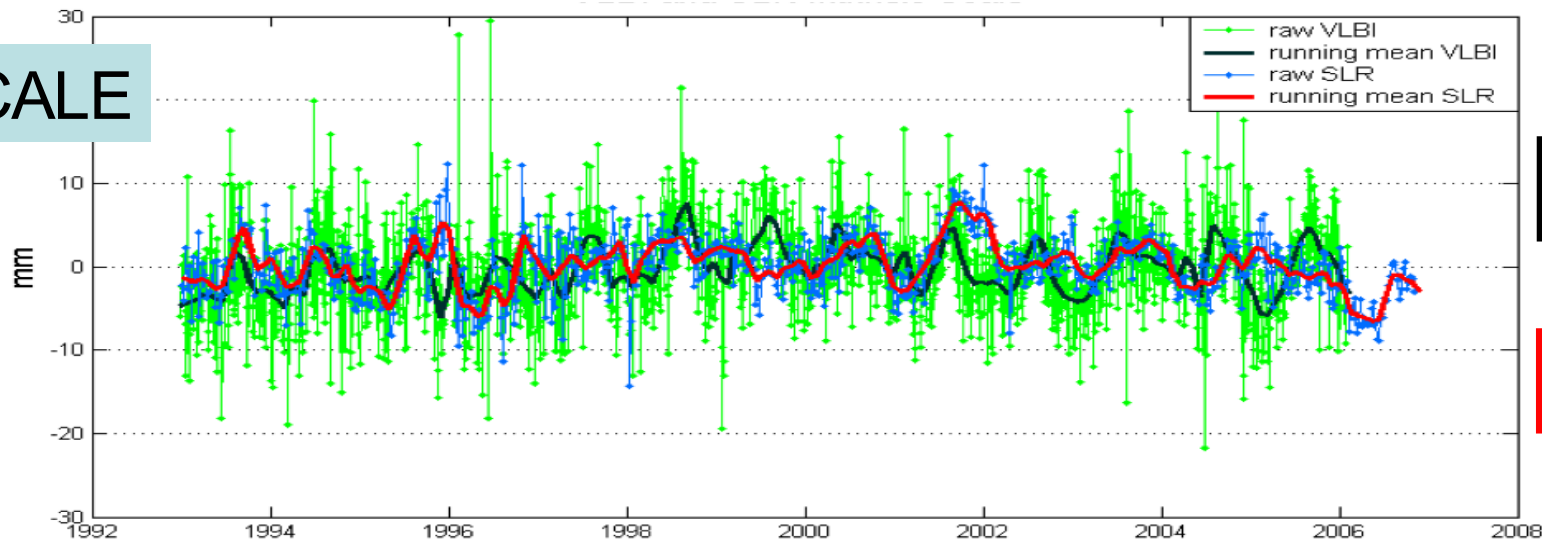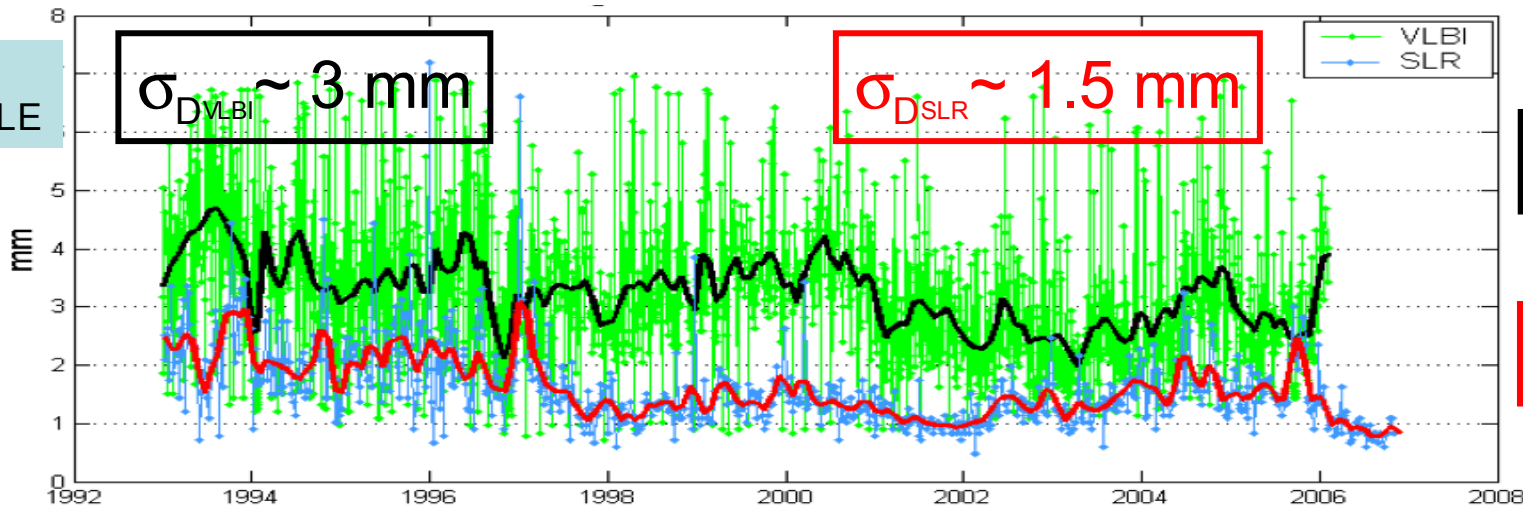
VLBI

SLR

SLR Scale Evolution

Intrinsic SLR scale from ITRF combination

RMS = 0.3 ppb (≈ 2 mm)

SLR scale from ILRS combination centers

LAGEOS POD with ITRF2005
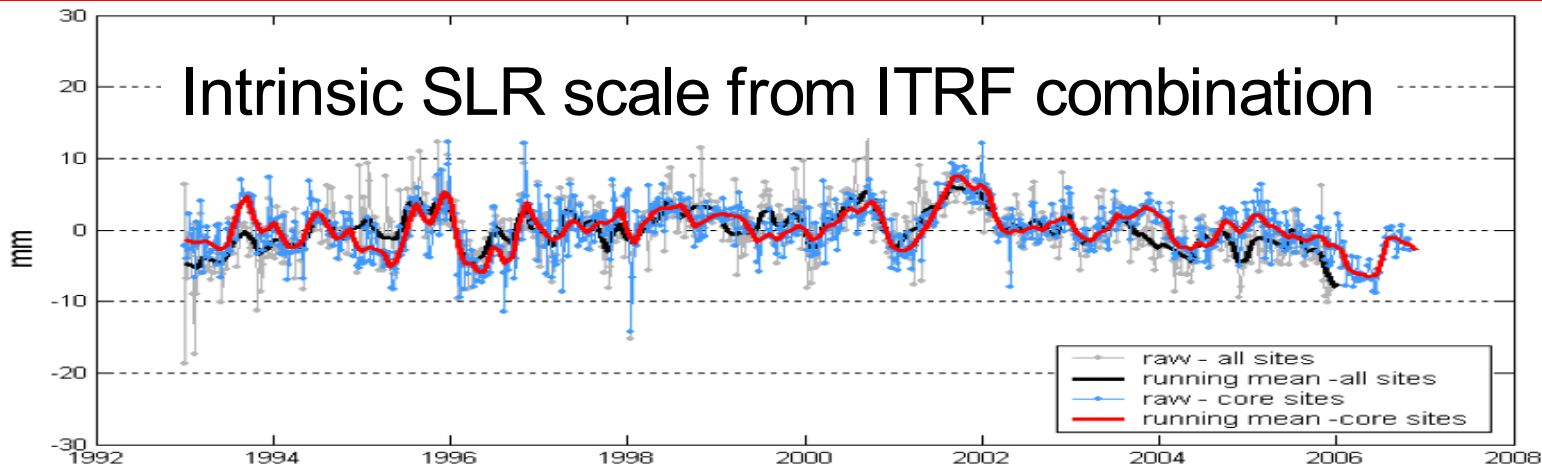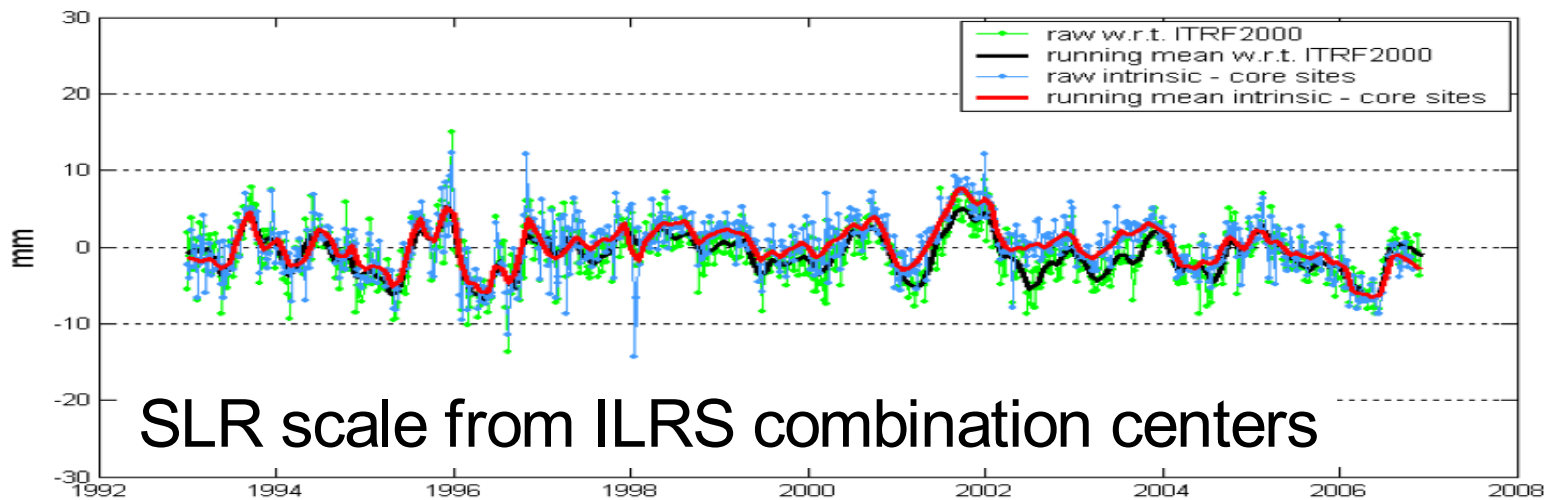
SLR residual RMS for 1992-2005 using 60-day arcs, GGM02C, Mendes/Pavlis refraction model, 17-station 'core' network

	ITRF2000	ITF2005	ITRF2005 (scaled -1.2 ppb)
SLR RMS (mm)	13.3 / 12.5	12.6 /12.3	12.0 / 11.4
Variance Decrease (mm^2)	-	18 / 5	33 / 26
SLR Mean (mm)	1	3	<1
YARAG Mean (mm)	3	6	<1

John Ries, CSR, Univ. of Texas

Absolute Origin of ITRF2005

- The use of the new TRF results in significant improvement in the SLR data reductions ONCE it is scaled to conform to SLR scale

CSR SLR analysis (LAGEOS 1/LAGEOS 2)*

	ITRF2000	ITRF2005	ITRF2005 (scaled -1 ppb)
X-drift (mm/yr)	-0.7	0.3	< 0.1
Y-drift (mm/yr)	-0.5	0.5	< 0.1
Z-drift (mm/yr)	-1.5	-0.9	-0.6

John Ries, CSR, Univ. of Texas   *** core network**

Implications for ILRS

- The goal of ILRS is to reach mm-SLR by the end of decade

- The most significant outcome that the release of ITRF2005 mandated is the need to revisit the error sources for SLR and the search for possible improvements, e.g.,

  - An updated improved refraction model (*adopted*)
  - Review of the accuracy of the CoM correction for the geodetic targets (*in progress*)
  - Extension of the analyzed data set to include all periods with quality tracking (*in progress*)
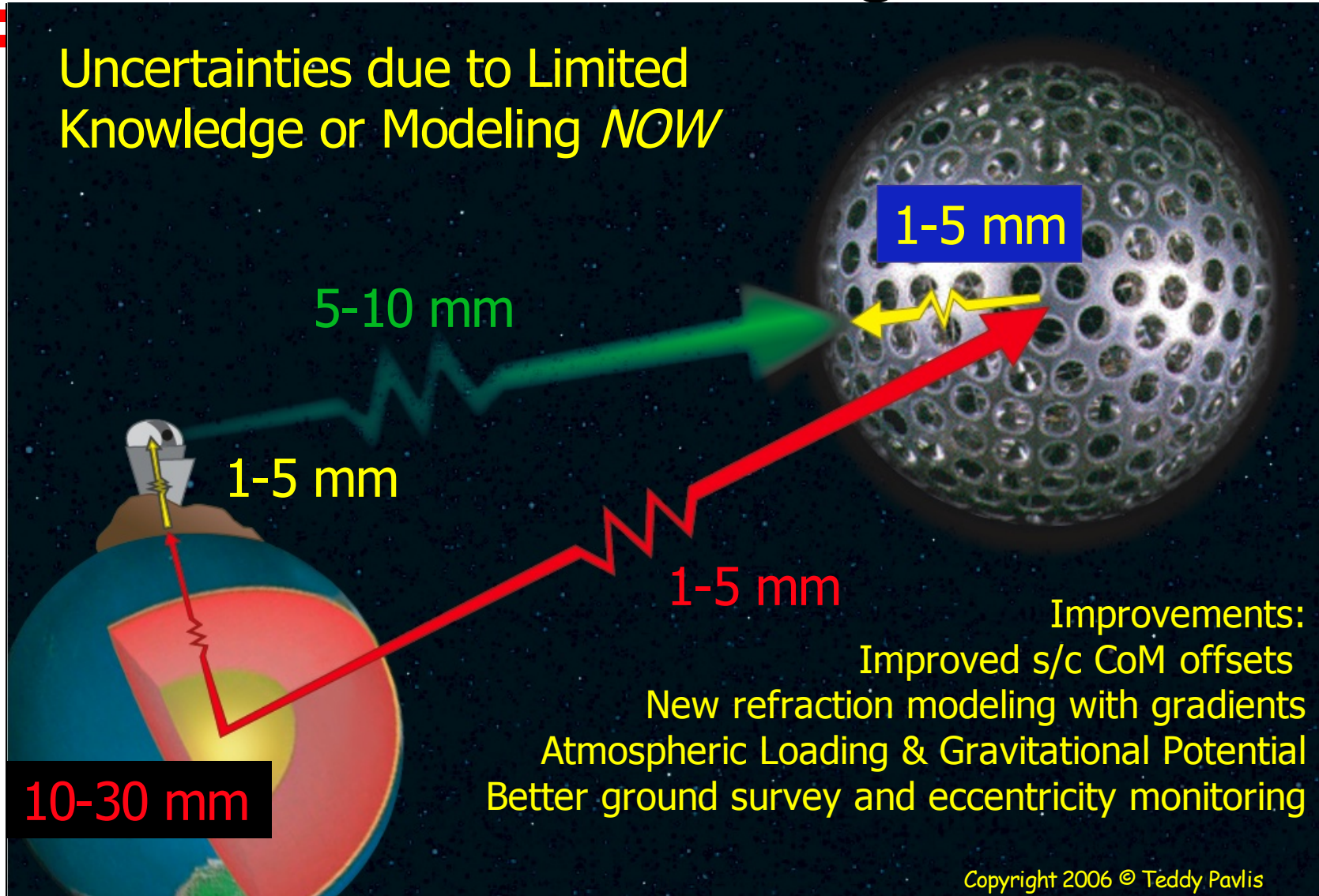
ITRF2005 for ILRS

- ITRS released (Dec. 6, 2006) a scaled version of <u>ONLY the SLR sites</u>, consistent with the intrinsic SLR scale, for use in SLR applications:

http://itrf.ensg.ign.fr/ITRF_solutions/2005/ITRF2005_SLR.php

- The ILRS AWG adopted the above as a reference TRF with the following extension in order to accommodate its needs for an accurate and consistent TRF across all available SLR data:
  - Add all missing sites from ITRF2000 after transformation to ITRF2005_SLR
  - Add best current estimates of new SLR sites (since 2006)

SLR Error Budget

Uncertainties due to Limited Knowledge or Modeling *NOW*

1-5 mm

5-10 mm

1-5 mm

1-5 mm

10-30 mm

Improvements:
Improved s/c CoM offsets
New refraction modeling with gradients
Atmospheric Loading & Gravitational Potential
Better ground survey and eccentricity monitoring

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LAGEOS CoM Range

$$1/2 \; CoM \; Range \approx 1 \; ppb$$

Atmospheric Ray Tracing (ART)
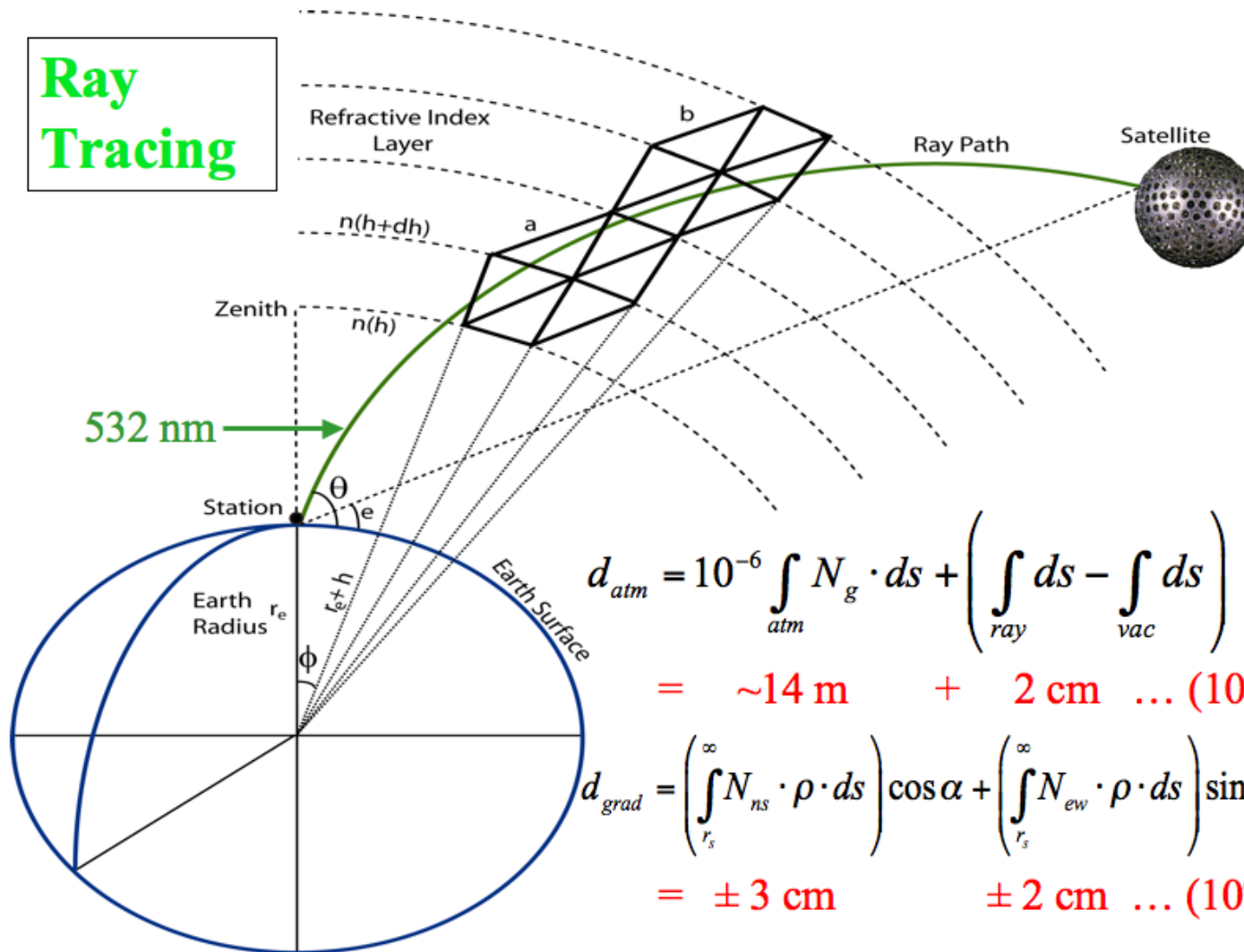
$$d_{atm} = 10^{-6} \int\limits_{atm} N_g \cdot ds + \left(\int\limits_{ray} ds - \int\limits_{vac} ds \right)$$

$$= \quad \sim 14\,\text{m} \quad + \quad 2\,\text{cm} \quad \dots (10°)$$

$$d_{grad} = \left(\int\limits_{r_s}^{\infty} N_{ns} \cdot \rho \cdot ds \right) \cos\alpha + \left(\int\limits_{r_s}^{\infty} N_{ew} \cdot \rho \cdot ds \right) \sin\alpha$$

$$= \quad \pm 3\,\text{cm} \quad \quad \pm 2\,\text{cm} \quad \dots (10°)$$

SLR Error Reduction with ATR

Method	ΔBias (mm)	$\Delta\sigma^2$ (%)
AIRS		
RT_{grad}	0.3 ± 0.3	14.0
RT_{3d}	0.9 ± 1.1	**24.8**
ECMWF		
RT_{grad}	0.1 ± 0.5	10.8
RT_{3d}	0.6 ± 1.2	**22.5**
NCEP		
RT_{grad}	0.1 ± 0.1	7.1
RT_{3d}	n/a	n/a

Hulley, G.C, and E.C. Pavlis (2007), A ray tracing technique for improving Satellite Laser Ranging (SLR) atmospheric delay corrections, including the effects of horizontal refractivity gradients, *J. Geophys. Res.,* **in print**

Internal SLR-only "ILRS" TRF

- SLR analysis centers provided IERS always with "SLR" lumped normal equations from analysis of several years for the development of ITRF

- NASA Goddard, ASI, CSR/UTEX, DGFI, etc. were consistent contributors up to ITRF2000

- The expertise and mechanics to do SLR-only TRFs is available within the ILRS and we will exercise it in order to track the evolution of the SLR TRF on a weekly basis

- JCET has consistently released a weekly updated SLR-only TRF since 2001 on a weekly basis

1976-06 SLR-ONLY SSC (JCET) 06 L97 Transformations

vs. ITRF2000	vs. ITRF2005
Dx = -8.82 +/- 1.02 [mm]	Dx = 1.25 +/- 0.91 [mm]
Dy = 3.21 +/- 1.01 [mm]	Dy = 8.37 +/- 0.91 [mm]
Dz = -5.65 +/- 0.95 [mm]	Dz = -6.59 +/- 0.86 [mm]
Ds = 0.52 +/- 0.15 [ppb]	**Ds = -0.87 +/- 0.13 [ppb]**
Rx = -0.24 +/- 0.04 [mas]	Rx = 0.05 +/- 0.04 [mas]
Ry = 0.06 +/- 0.04 [mas]	Ry = -0.07 +/- 0.04 [mas]
Rz = 0.15 +/- 0.03 [mas]	Rz = 0.32 +/- 0.03 [mas]
Dxd = 0.75 +/- 0.95 [mm/y]	Dxd = -1.22 +/- 0.85 [mm/y]
Dyd = 0.56 +/- 0.94 [mm/y]	Dyd = 1.37 +/- 0.85 [mm/y]
Dzd = 3.10 +/- 0.73 [mm/y]	Dzd = 1.89 +/- 0.65 [mm/y]
Dsd = -0.10 +/- 0.14 [ppb/y]	**Dsd = 0.05 +/- 0.12 [ppb/y]**
Rxd = 0.12 +/- 0.03 [mas/y]	Rxd = 0.12 +/- 0.03 [mas/y]
Ryd = -0.02 +/- 0.03 [mas/y]	Ryd = 0.02 +/- 0.03 [mas/y]
Rzd = 0.02 +/- 0.03 [mas/y]	Rzd = 0.01 +/- 0.03 [mas/y]

Similar relationship of SLR-only TRF to ITRF2005
~ -1 ppb & +0.05 ppb/yr (~6 mm & 0.4 mm/yr)

Summary

- Increased accuracy requirements for ITRF dictate an increase in the accuracy of the contributions
- The ILRS recognizes the need for improved modeling in the data reduction process and
  - It has adopted improved refraction models
  - It is reanalyzing all LAGEOS data since 1976
  - It is refining the CoM corrections for LAGEOS
  - It is establishing an SLR-only TRF product
  - It is revisiting the estimation of "few-mm-level" biases once we have implemented critical model improvements (e.g. CoM offsets, atmospheric loading, temp. gravity, etc.)

Outlook

- Improvements will be reviewed at the time of the IUGG in Perugia

- Improved reanalysis products will be available by the end of the year

- Additional products will be initiated during the remainder of the year as improvements are introduced in the operational product (e.g. orbit files, weekly SLR-only TRF, geocenter series, 3D ATR refraction delays, etc.)

ITFR2000

ITFR2000 + SLR geocenter   ≈   ITFR2005

Geocenter with ITRF2005

- ITRF2005D exhibits similar performance to that of an appropriately scaled ITRF2005P (~1 ppb) with minor noise differences

JR/CSR Geocenter Series From Two TRFs:

ITRF2005P*   **ITRF2005D**

ILRS TRF Scale

- No systematic scale variations seen in the ILRS CC products [main (A) or back-up (B)]

ILRS-A

ILRS-B

RMS scale 0.5 ppb over 13+ years