Atmospheric Refraction at Optical Wavelengths: Problems and Solutions

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Outline

- Background
- Zenith delay models
- Mapping Functions
- Wavelength dependence
- Conclusions

Atmospheric Delay

$$d_{atm} = \int_{ray} (n-1)\, ds + \left[\int_{ray} ds - \int_{vac} ds \right]$$

Propagation Delay

Ray Bending

Atmospheric Delay

$$d_{trop} = d_h^z \cdot m_h(\varepsilon) + d_w^z \cdot m_w(\varepsilon)$$

Hydrostatic
Zenith Delay

Hydrostatic
Mapping Function

Wet
Zenith Delay

Wet
Mapping Function

Atmospheric Delay

$$d_{atm} = d_{atm}^{z} \cdot m_t(\varepsilon)$$

Mapping Function

Zenith Total Delay

$$d_{atm}^{z} = 10^{-6} \int_{r_s}^{r_a} N \, dz$$

Zenith Delay Models

- Marini-Murray (1973)
- Saastamoinen (1973) – Hydrostatic and Wet
- Yan and Wang (1999) – Hydrostatic and Wet

	P	T	e (RH)	φ	H	λ
MM	✓	✓	✓	✓	✓	✓
SA	✓		✓	✓	✓	✓
YW	✓	✓	✓	✓	✓	✓

Mapping Functions

- Marini-Murray * (1973) – Total **(includes ZD determination)**
- Saastamoinen * (1973) – Hydrostatic and Wet
- Yan and Wang* (1999) – Total
- FCULA (2002) * * – Total (uses surface Temperature)
- FCULB (2002) * * – Total (no meteorogical data)
- FCULZ (2002) * * – as FCULA, **(includes ZD determination with Saastamoinen model)**
  - * Wavelength dependent
  - ** Optimized for 532 nm

Ray-tracing

- Radiosonde data (1998) for North America and SW Pacific
- Group refractivity computed according IAG resolutions
- Computer procedures described in Ciddor (1999) and Ciddor and Hill (1999)
- Water vapor pressure computed using Davis (1992)
- 3 elevation angles: 15º, 10º, 6º
- Wavelengths: 355nm , 423nm, 532 nm, 847 nm, 1064 nm

New Mapping Functions (2000)

GEOPHYSICAL RESEARCH LETTERS, VOL. 29, NO. 10, 10.1029/2001GL014394, 2002

Improved mapping functions for atmospheric refraction correction in SLR

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Notation and Correction

- Mapping function results in **CENTIMETERS**
- Zenith delay results in **MILLIMETERS**

Table 3. Statistics for the Marini-Murray and Saastamoinen ZD Models (Total Zenith Delay) **(mm)**

ϵ (°)	Model	mean	std	r.m.s.	max
90°	M-M	1.19	0.58	1.33	2.00
90°	SAAS	1.18	0.56	1.30	2.04

New Mapping Function Comparisons

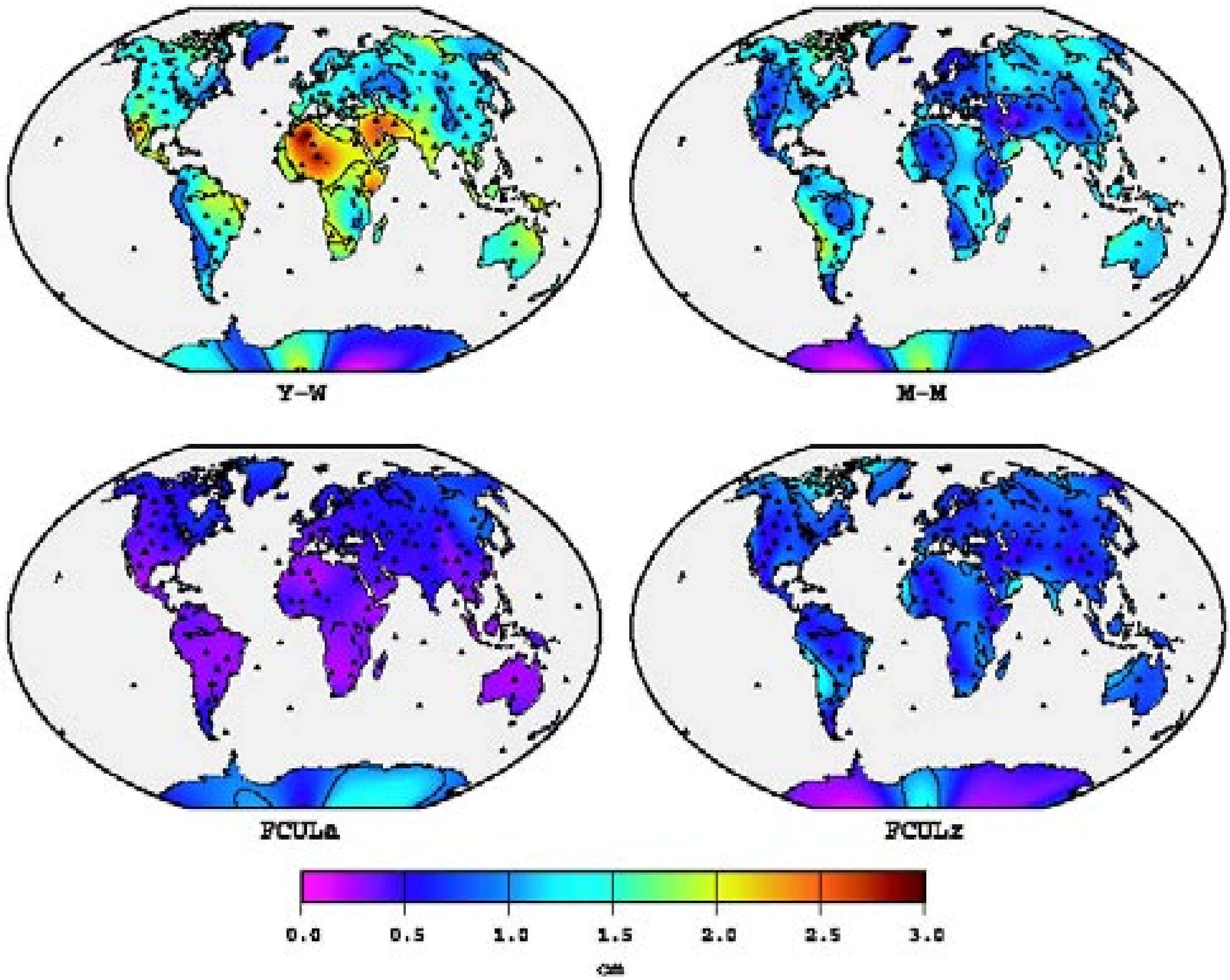
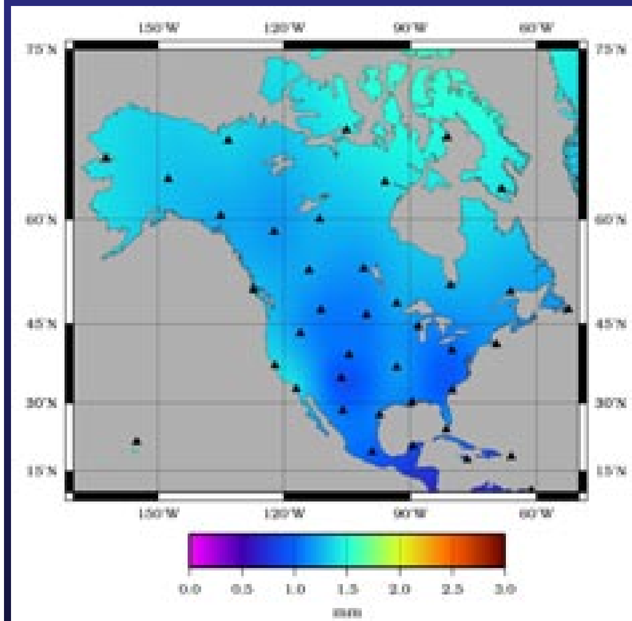


Figure 1. Two-year average r.m.s. of the differences (model minus ray tracing), at 10° elevation angle. Plots on the left represent MF errors for FCULa and Y-W; plots on the right represent the combined error of ZD and MF for M-M and FCULz (see text for details). Small triangles represent the locations of the radiosonde sites used in this study.

Assessment of Wavelength Dependence of New Models

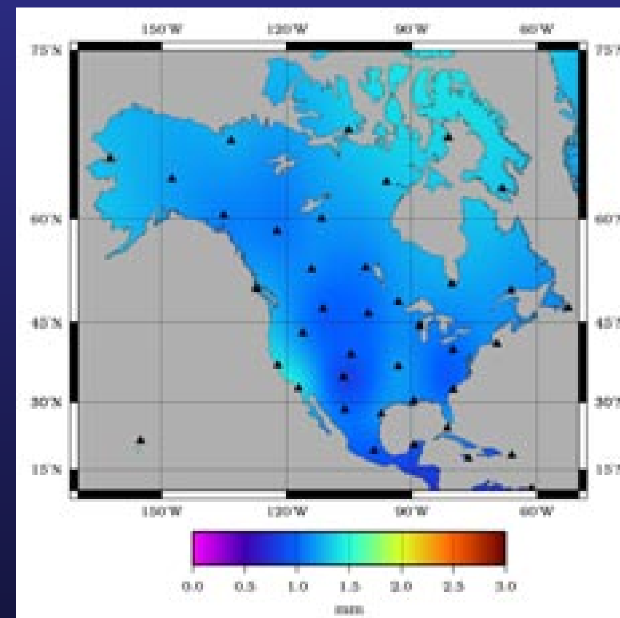
Radiosonde Locations

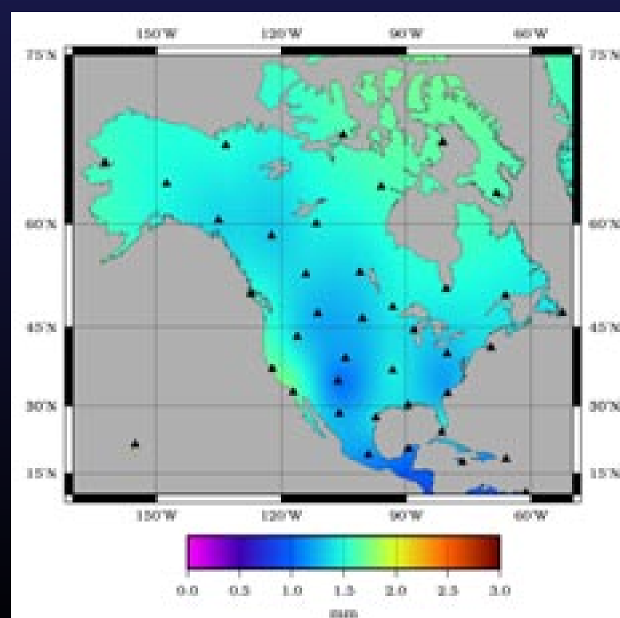
Zenith delay models (532 nm)



MM

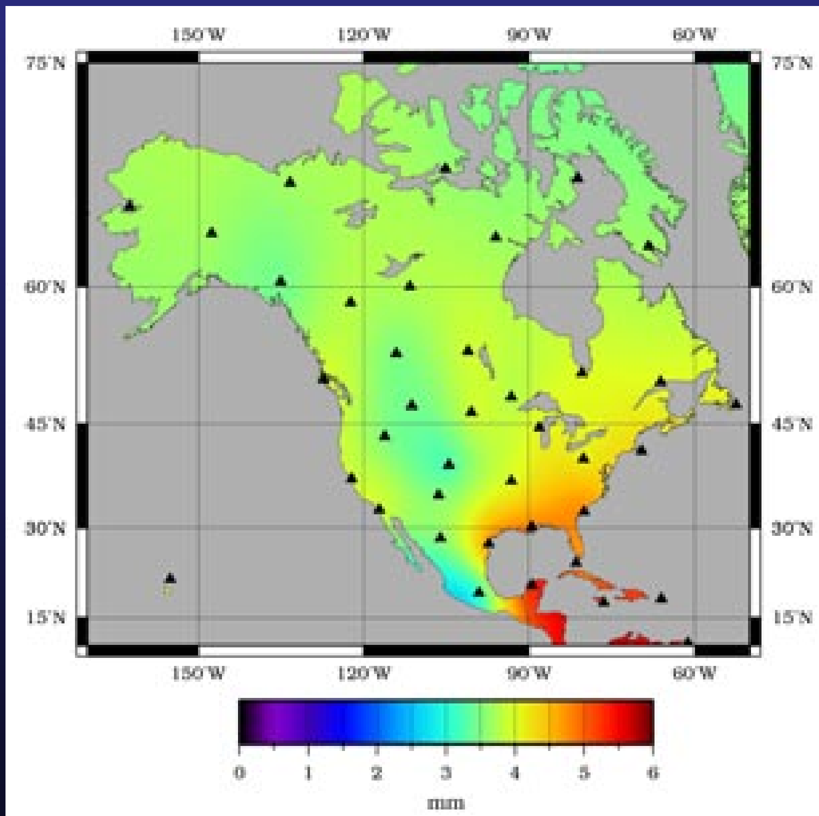
SA



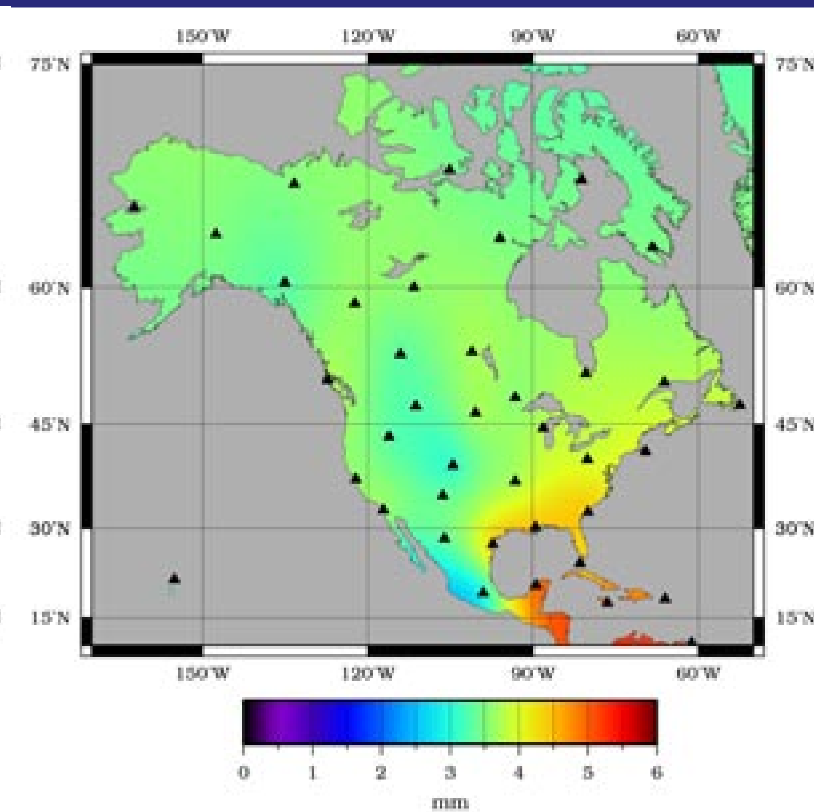


YW

Zenith delay models (355 nm)

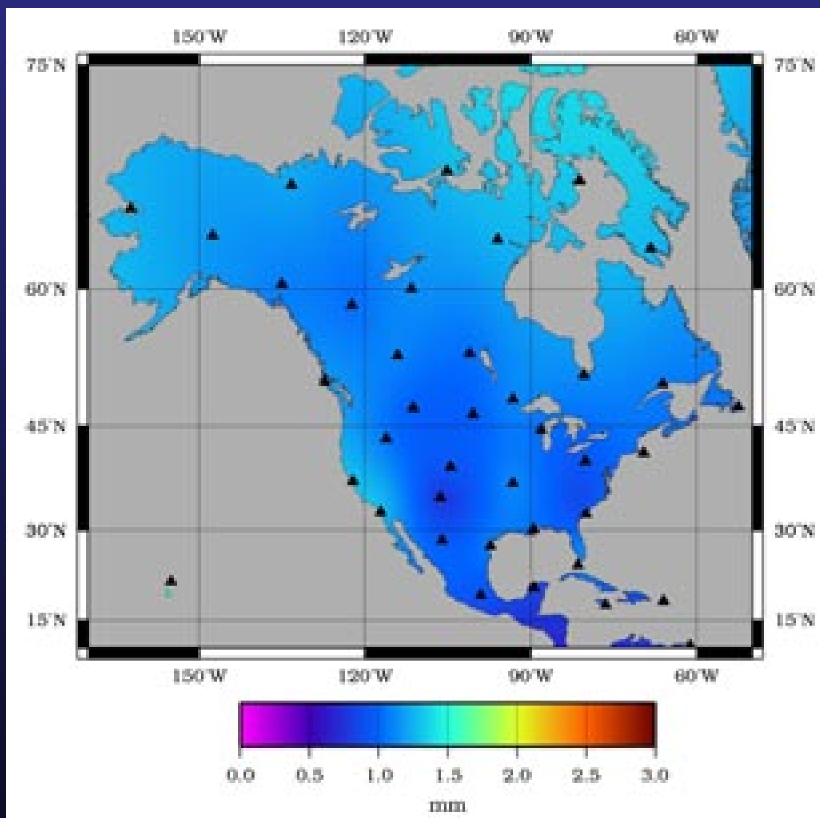


MM

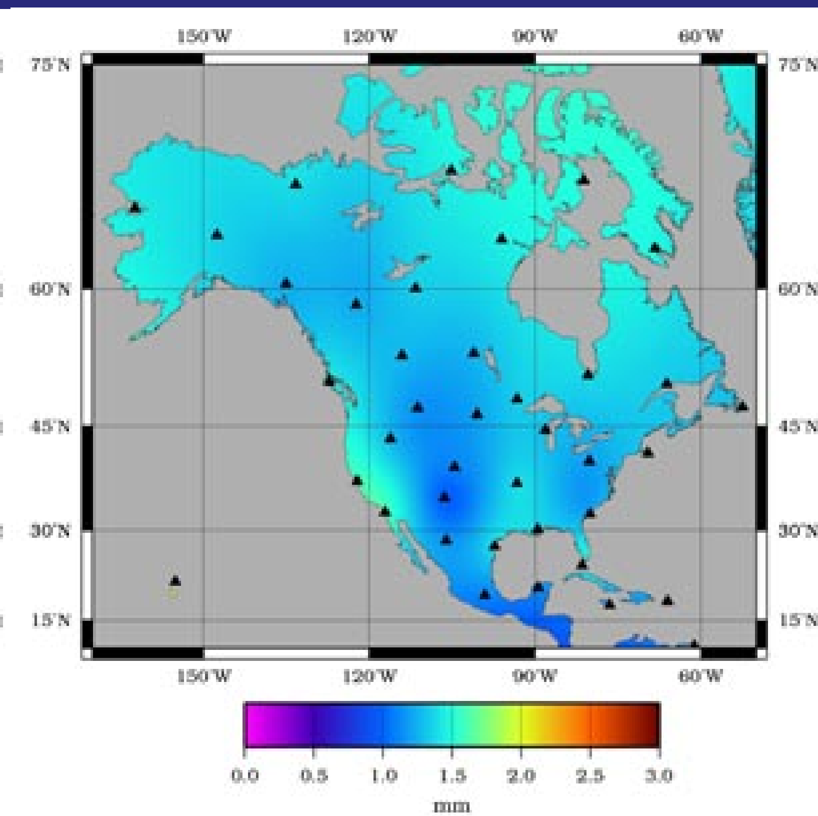


YW

Zenith delay models (1064 nm)



MM



YW

RMS for Zenith Delay Models

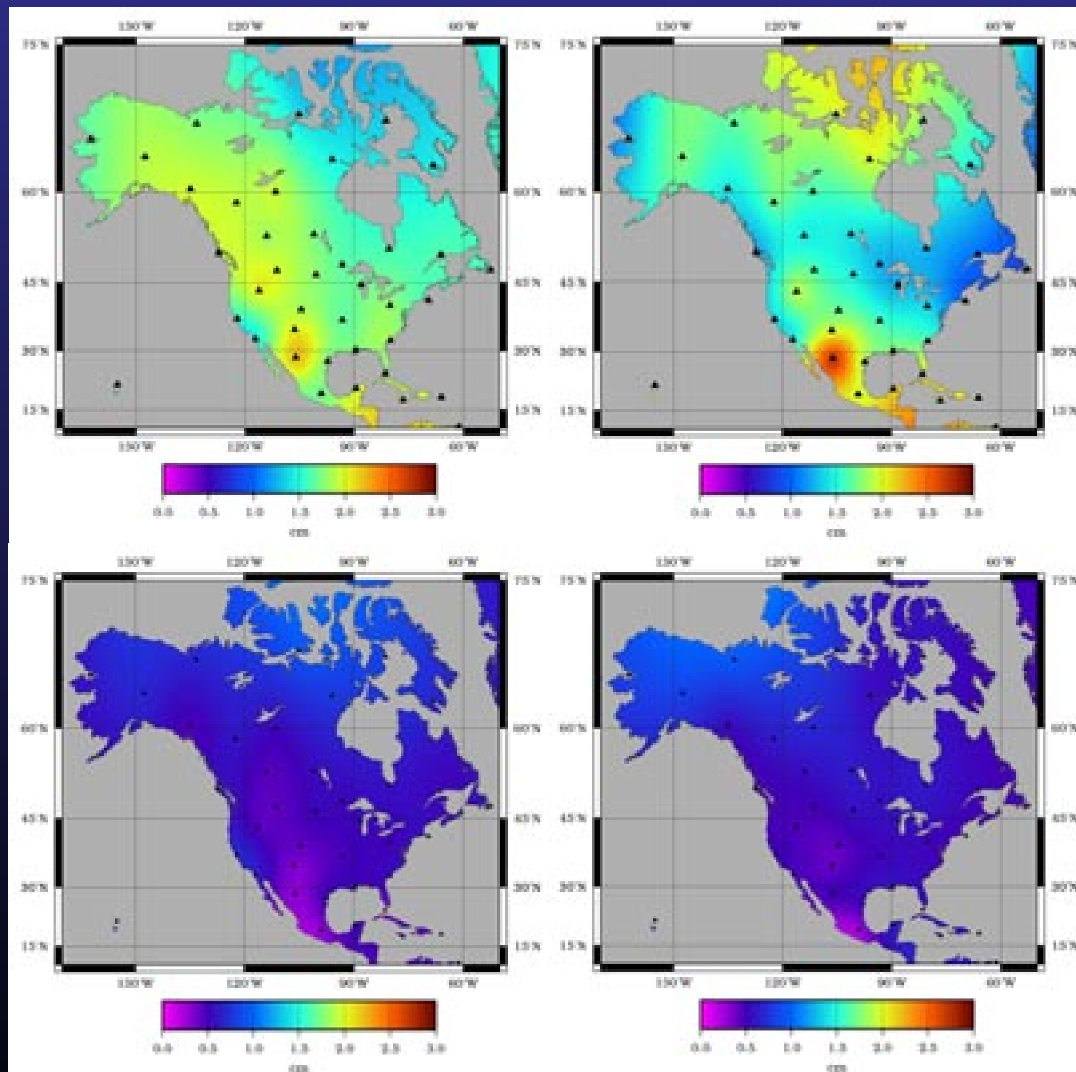
Model minus Ray Tracing (mm)

λ (nm)	MM	SA	YW
355	4.2	7.6	4.0
423	0.8	1.6	0.7
532	1.2	1.2	1.4
847	1.2	1.2	1.4
1064	1.1	0.9	1.3

Mapping Functions (355 nm, e = 10º)

MM

YW



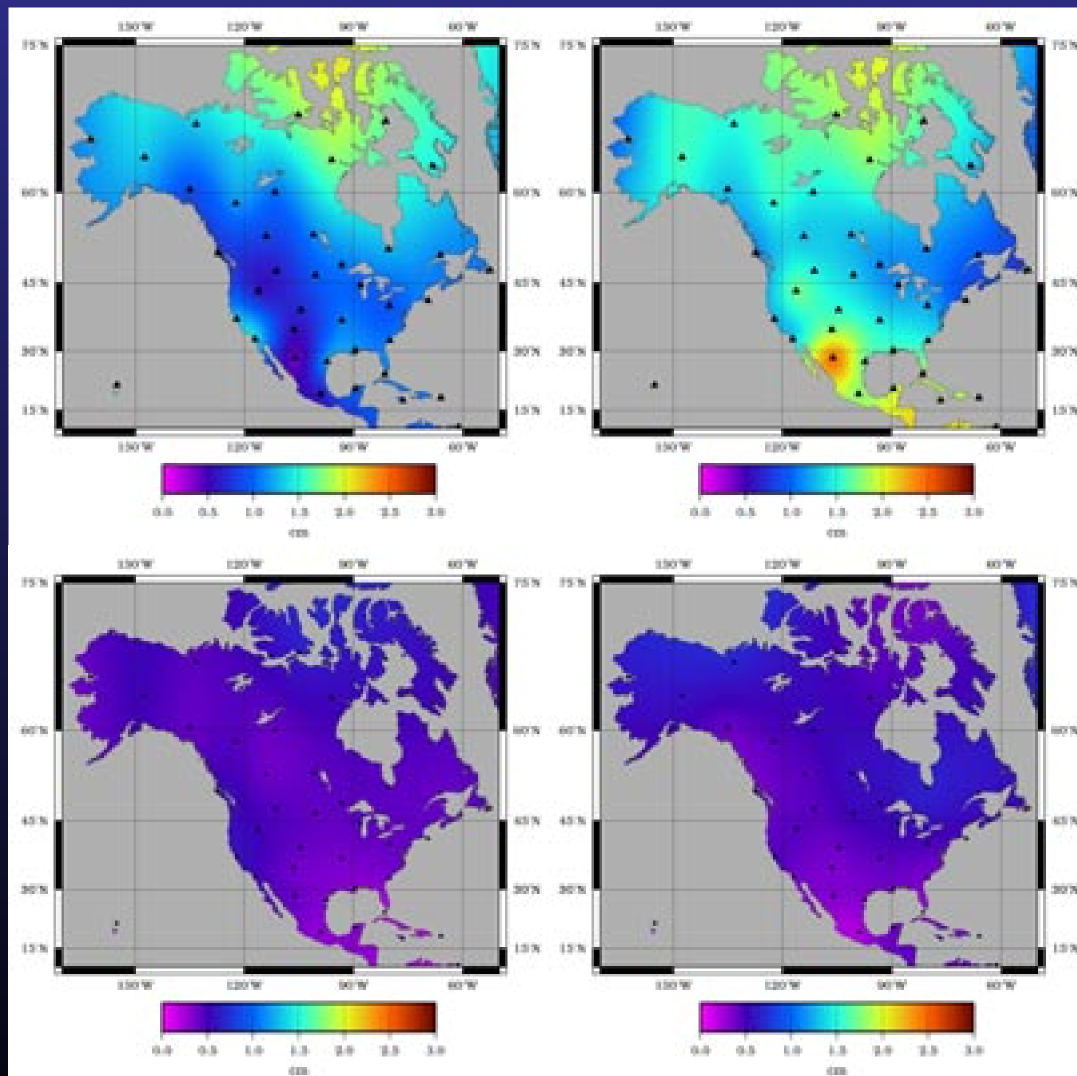
FCULA

FCULB

Mapping Functions (532 nm, $e = 10^{\circ}$)

MM

YW



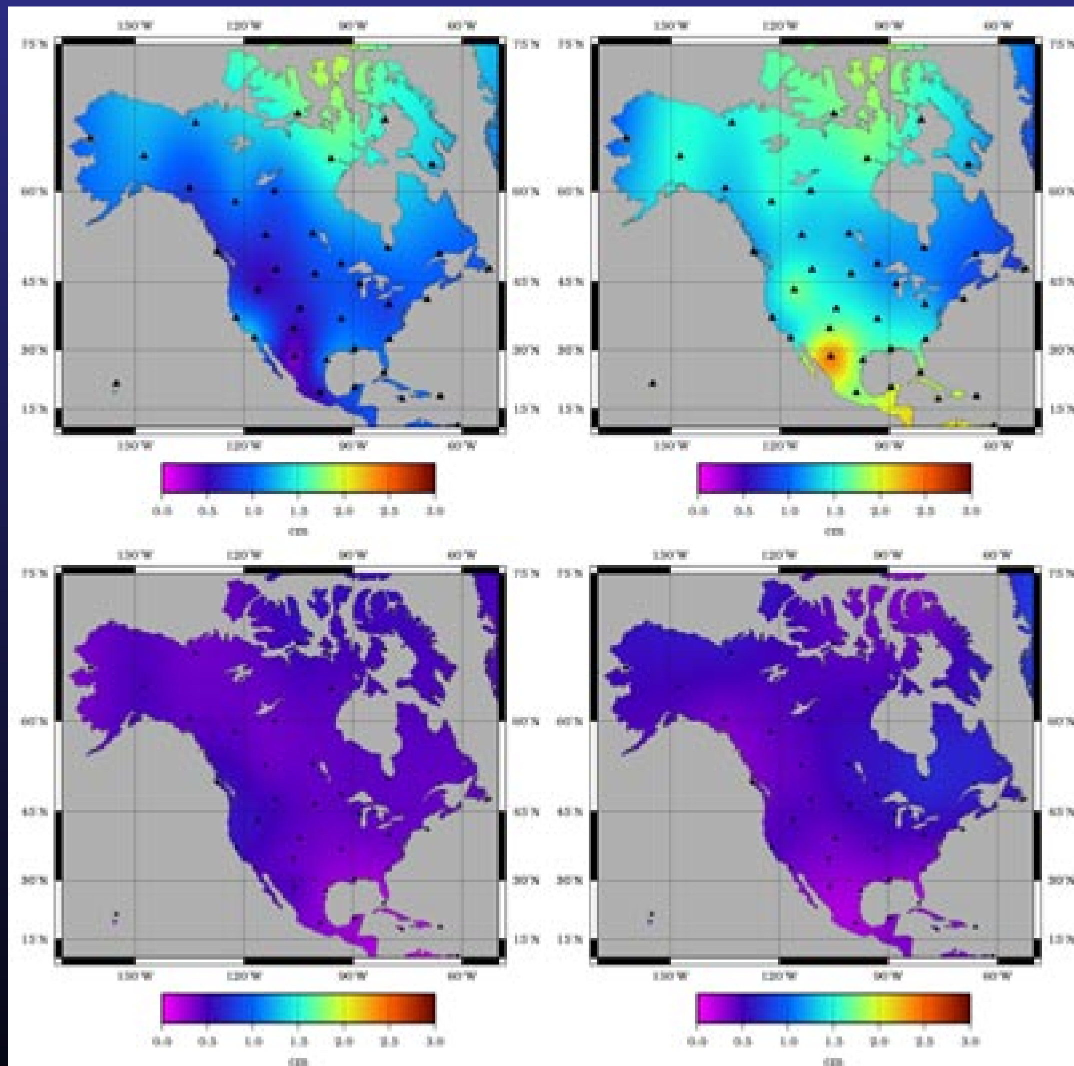
FCULA

FCULB

Mapping Functions (847 nm, e = 10º)

MM

YW



FCULA

FCULB

RMS for Mapping Functions ($\varepsilon = 10^{o}$)

Model minus Ray Tracing (cm)

λ (nm)	MM	YW	SA	FCULA	FCULB	FCULZ
355	1.77	1.72	3.04	0.55	0.59	3.83
423	0.79	1.65	2.48	0.46	0.51	0.75
532	1.14	1.56	2.16	0.41	0.46	0.82
847	1.05	1.56	2.05	0.39	0.45	0.75
1064	0.98	1.77	2.06	0.39	0.45	0.62

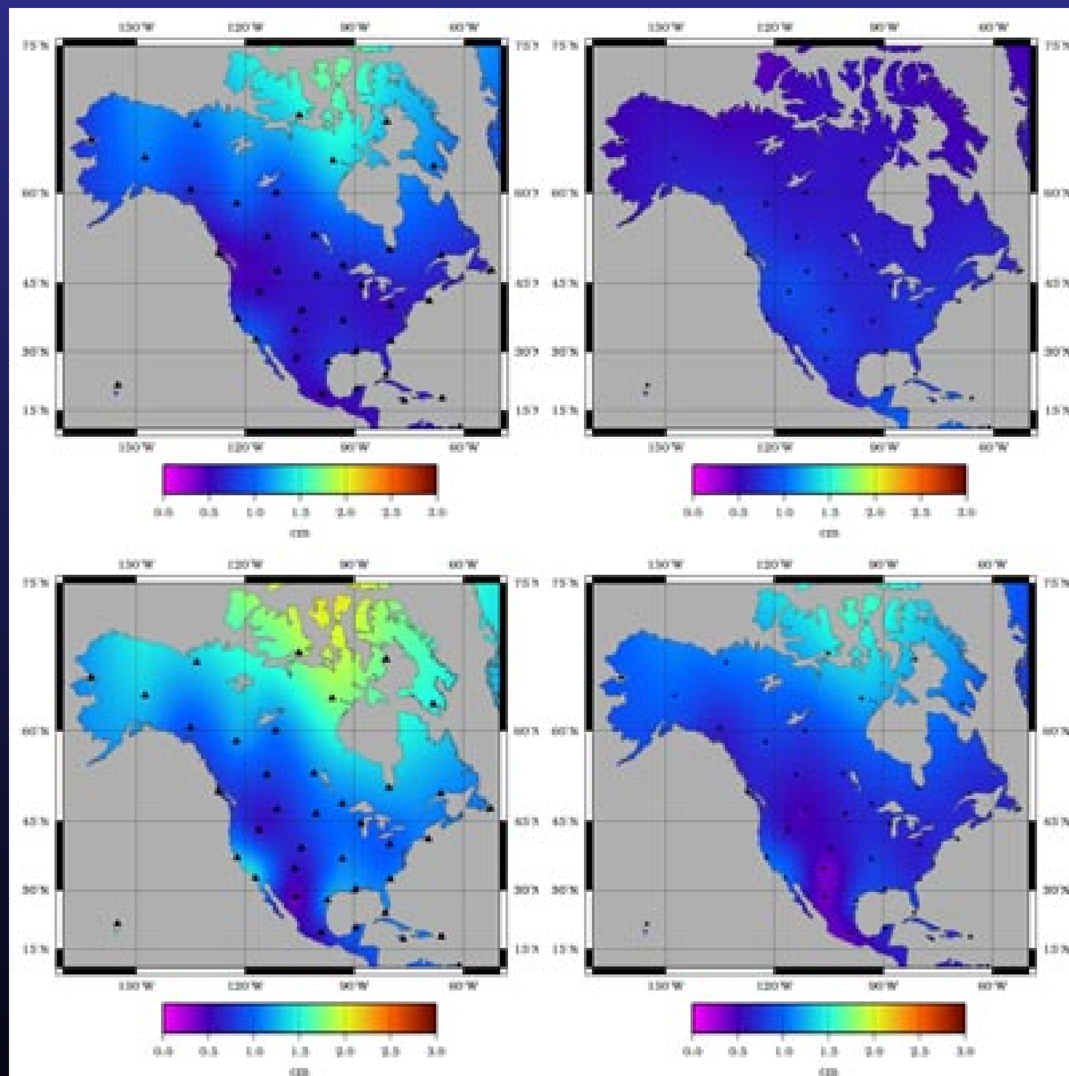
MM vs FCULZ (e = 10º)

MM, 423 nm

FCULZ, 423 nm

MM, 532 nm

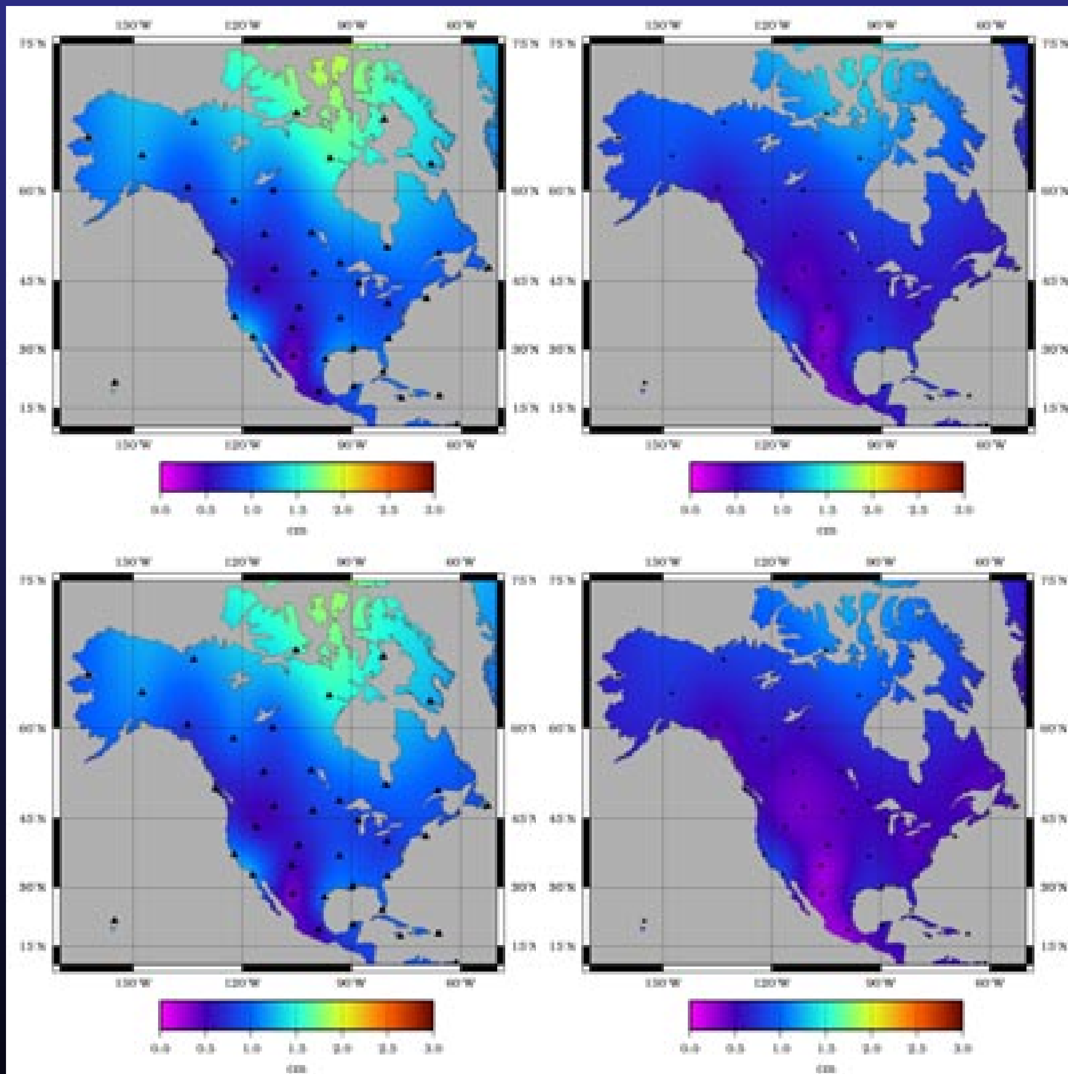
FCULZ, 532 nm



MM vs FCULZ (e = 10º)

MM, 847 nm

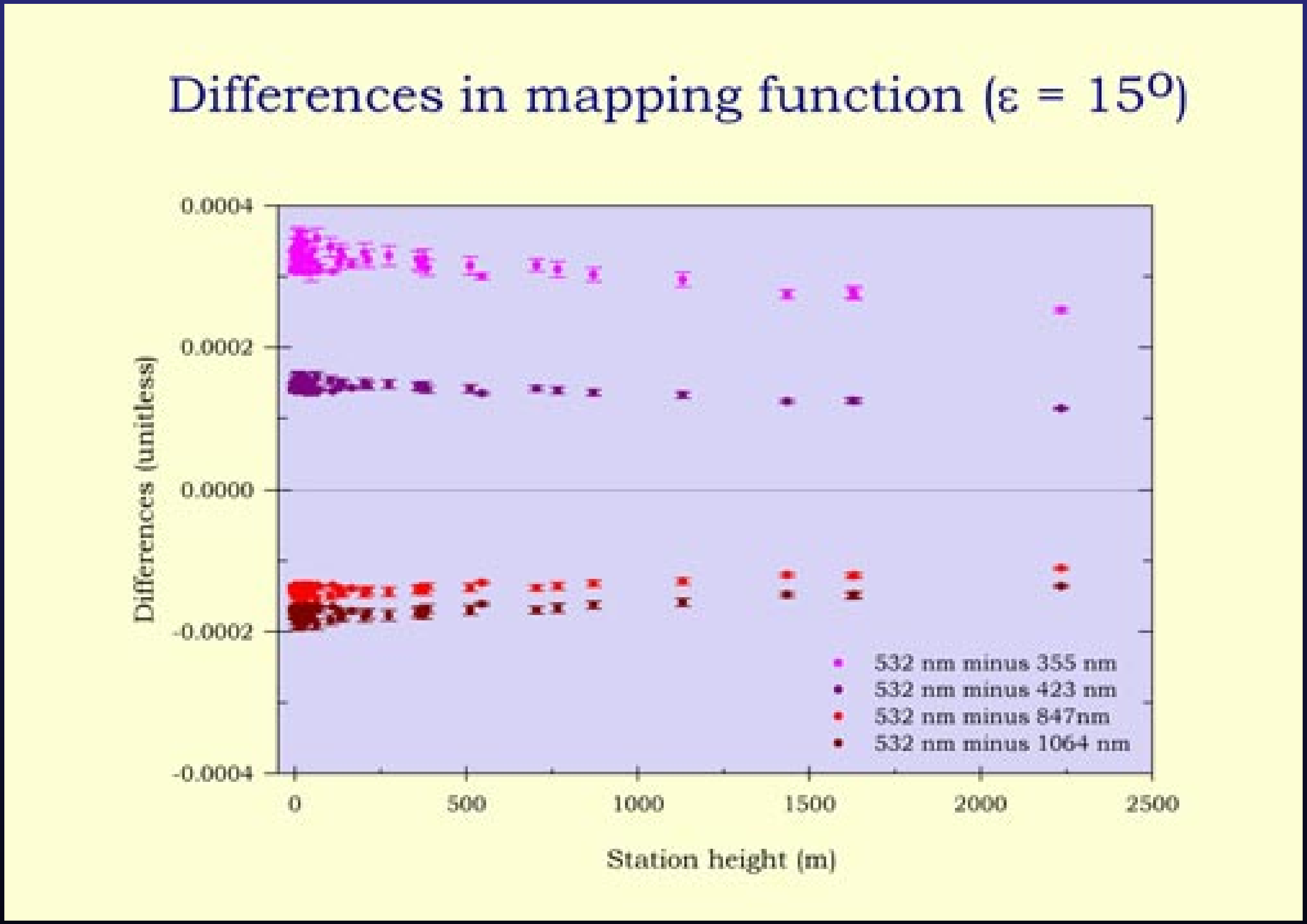
FCULZ, 847 nm



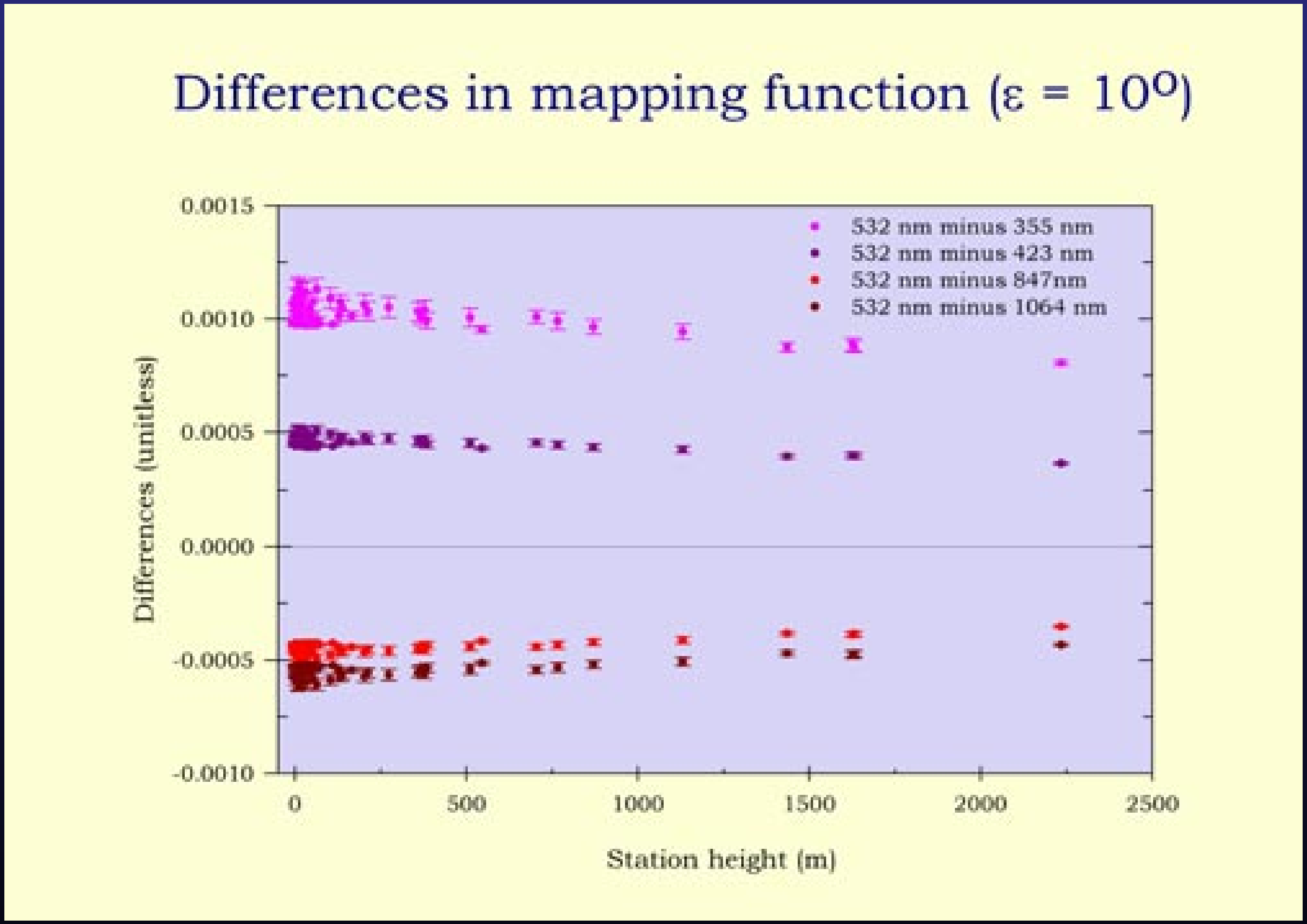
MM, 1064 nm

FCULZ, 1064 nm

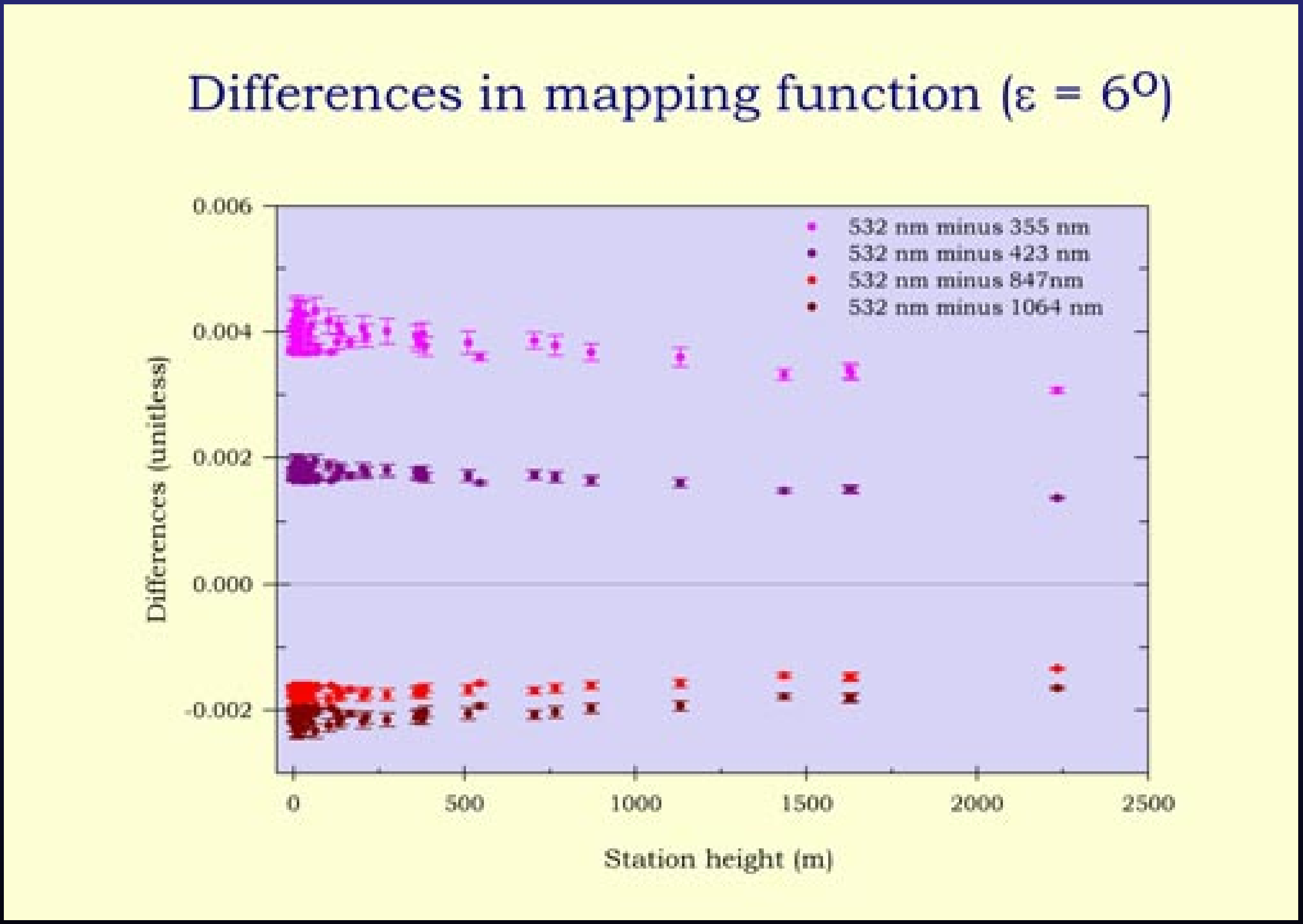
Changes in mapping function (e = 15º)



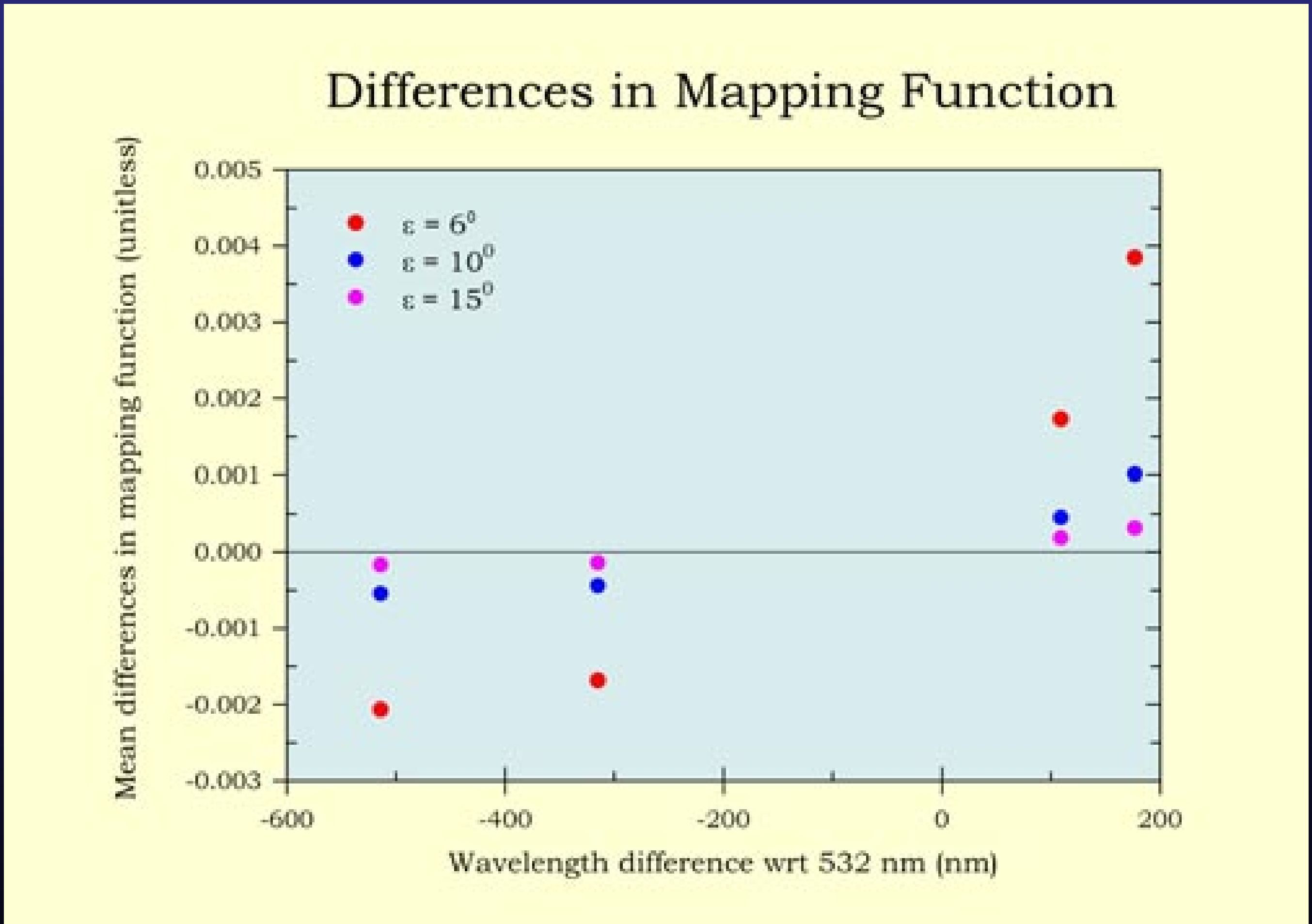
Changes in mapping factor (e = 10º)



Changes in mapping factor (e = 6º)



Changes in mapping factor



Some concluding remarks ...

- All zenith delay models present some bias (about twice the standard deviation)
- Bias is probably coming from deficiencies in zenith wet delay prediction (as YW is based in updated refraction model)
- Wavelength dependency of the mapping function is not significant for elevation angles above 10º
- Despite the optimization of the FCUL mapping functions for 532 nm, they do not degrade appreciably at other wavelengths; nevertheless, modeling of the wavelength/elevation dependence will be incorporated in a new version
- SLR testing with low elevation data is in progress