International Laser Ranging Service
Data Formats & Procedures Working Group

Agenda

Monday, April 16, 2007, 15:30-17:00

Vienna, Austria

Room: SM5 = Splinter Meeting Room 5, Splinter Meeting SPM72

1. Welcome and Introduction	Wolfgang Seemüller
2. Membership	Wolfgang Seemüller
3. Refraction Study Group	Erricos Pavlis
4. Formats Study Group	Randy Ricklefs
5. Revise of ILRS data format	Randy Ricklefs, Jan McGarry
6. "Pass" definition for GEO satellites	Randy Ricklefs, Chris Moore
7. Other Business, next meeting	All

International Laser Ranging Service
Data Formats & Procedures WG Members

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Co-Chairman: Randy Ricklefs

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RSG Report for Period
Oct. 2006 - April 2007

Erricos C. Pavlis

JCET/UMBC & NASA Goddard

EGU 2007

Vienna, Austria

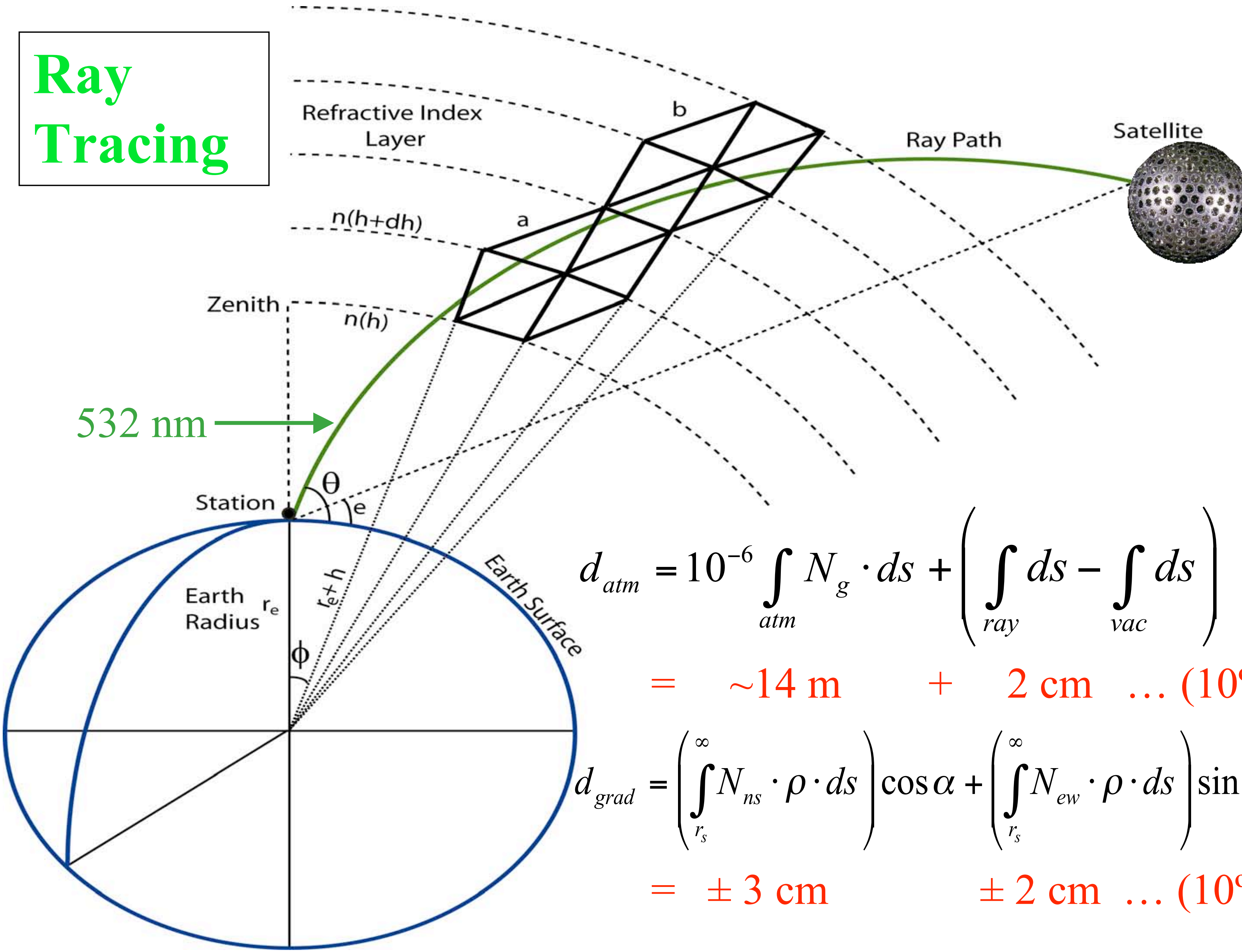
RSG News

- The AWG has adopted the M-P model since Jan. 1, 2007 for the operational product, and for the reanalysis product (1993-2007)
- Glynn Hulley completed the 3D ART study, and successfully defended PhD thesis
- Proposal to NASA for an operational product to deliver 3D ART corrections for all SLR data collected by the ILRS GLTN (pending)

Improved Refraction Corrections for Satellite Laser Ranging (SLR) by Ray Tracing Through Meteorological Data

Glynn Hulley
University of Maryland Baltimore County (UMBC)
Joint Center for Earth Systems Technology (JCET)
Doctoral Dissertation Defense
April 3, 2007

Ray Tracing



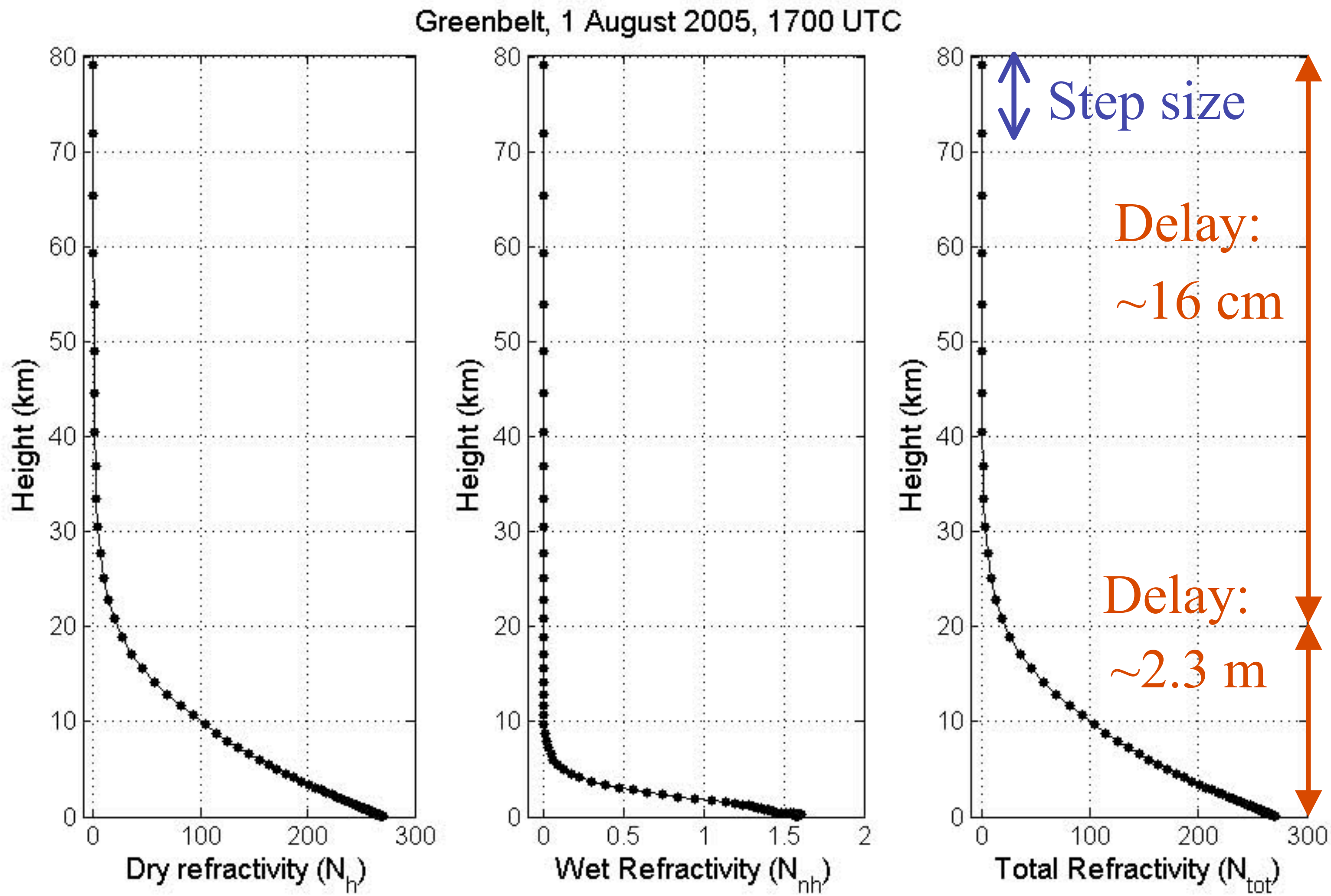
$$d_{atm} = 10^{-6}\int_{atm} N_g \cdot ds + \left(\int_{ray} ds - \int_{vac} ds\right)$$

$$= \quad \sim 14\text{ m} \quad + \quad 2\text{ cm} \quad \ldots (10^{o})$$

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

$$= \quad \pm 3\text{ cm} \quad \pm 2\text{ cm} \quad \ldots (10^{o})$$

Refractivity profiles



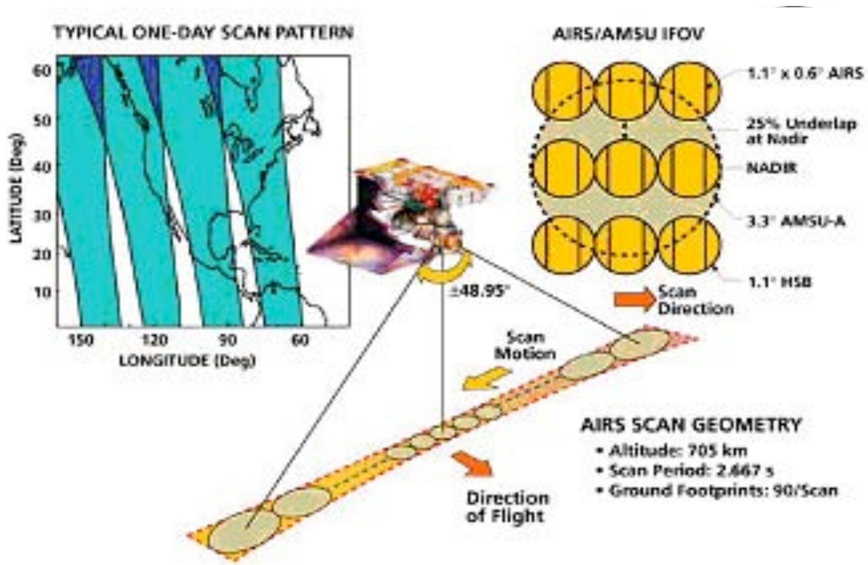
Data

- Atmospheric Infrared Sounder (AIRS)
  - 100 levels from surface to 0.1 mb
  - 0.5° resolution within grid
  - Data is obtained twice-daily (day-time, night-time)
- European Center for Medium Weather Forecasting
  - 60 levels from surface to 0.1 mb
  - 0.5° resolution
  - Analysis files at 00, 06, 12 and 18 hrs UTC
- National Center for Environment Prediction
  - 17 levels from surface to 10 mb
  - 2.5° resolution
  - Analysis files at 00, 06, 12 and 18 hrs UTC

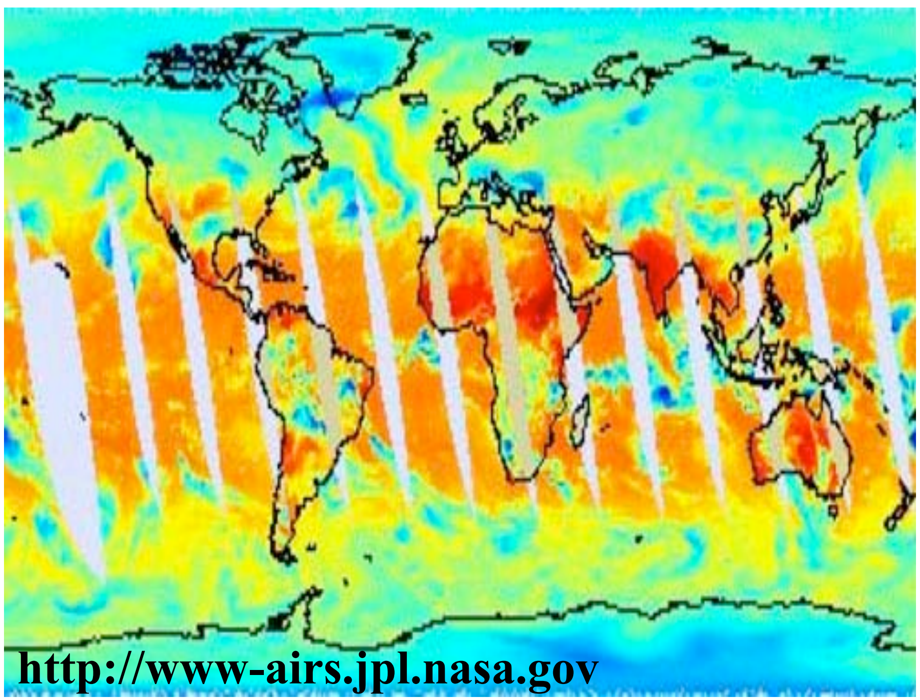
AIRS coverage

Granule:

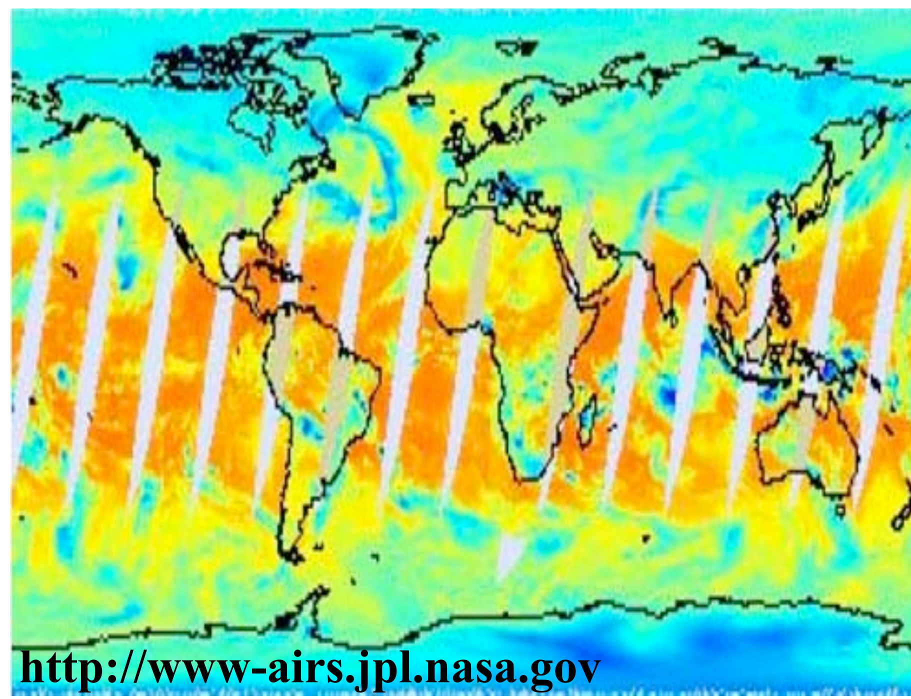
- 1650 km x 2300 km
- ± 49.5º scan



Ascending (day-time)



Descending (night-time)



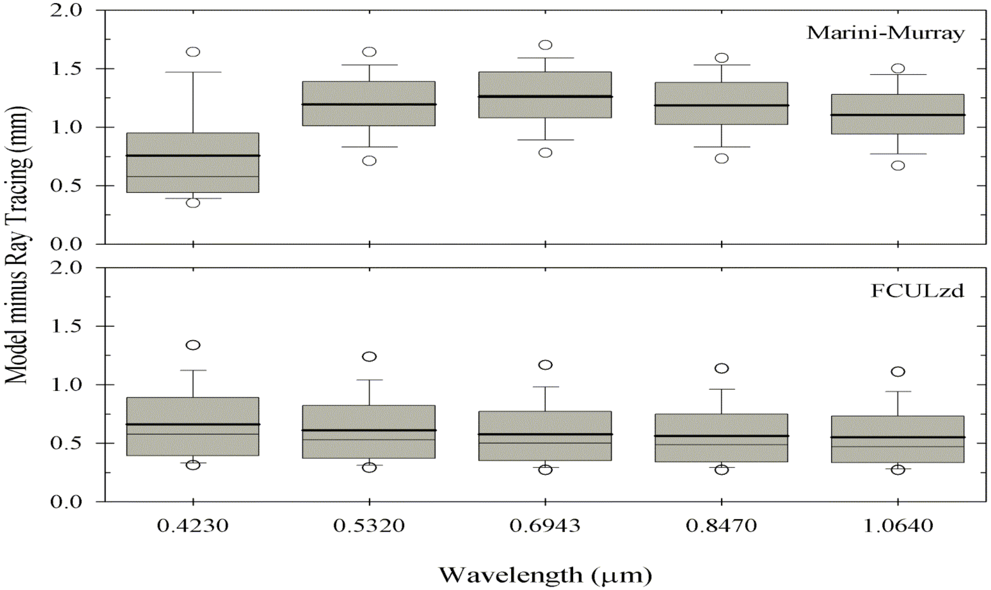
Ray Tracing and Delay Model Comparisons

- Delay models: $d_{atm} = d_{atm}^{z}\, m(e)$
- d^{z}_{atm} => FCULzd – *Mendes and Pavlis* [2004]
- m(e) => FCULa and FCULb – *Mendes et al.* [2002]
  1. FCULzd · FCULa = FCULzda
  2. FCULzd · FCULb = FCULzdb
  3. Marini-Murray (M-M)
- Models assume spherical symmetry (no azimuth dependence)
- Isotropic mapping functions
- Comparisons with 2D ray tracing at 532 nm
- 10 SLR stations during 2004 and 2005
- Models developed by ray tracing with radiosonde data

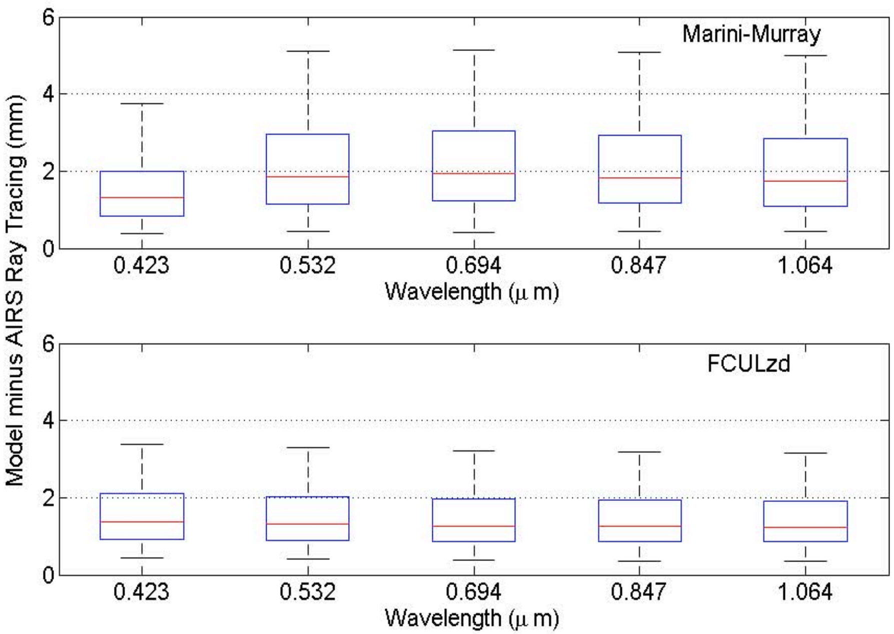
*

Zenith Delay (d^z_{atm}):

RMS values of Model minus ray tracing



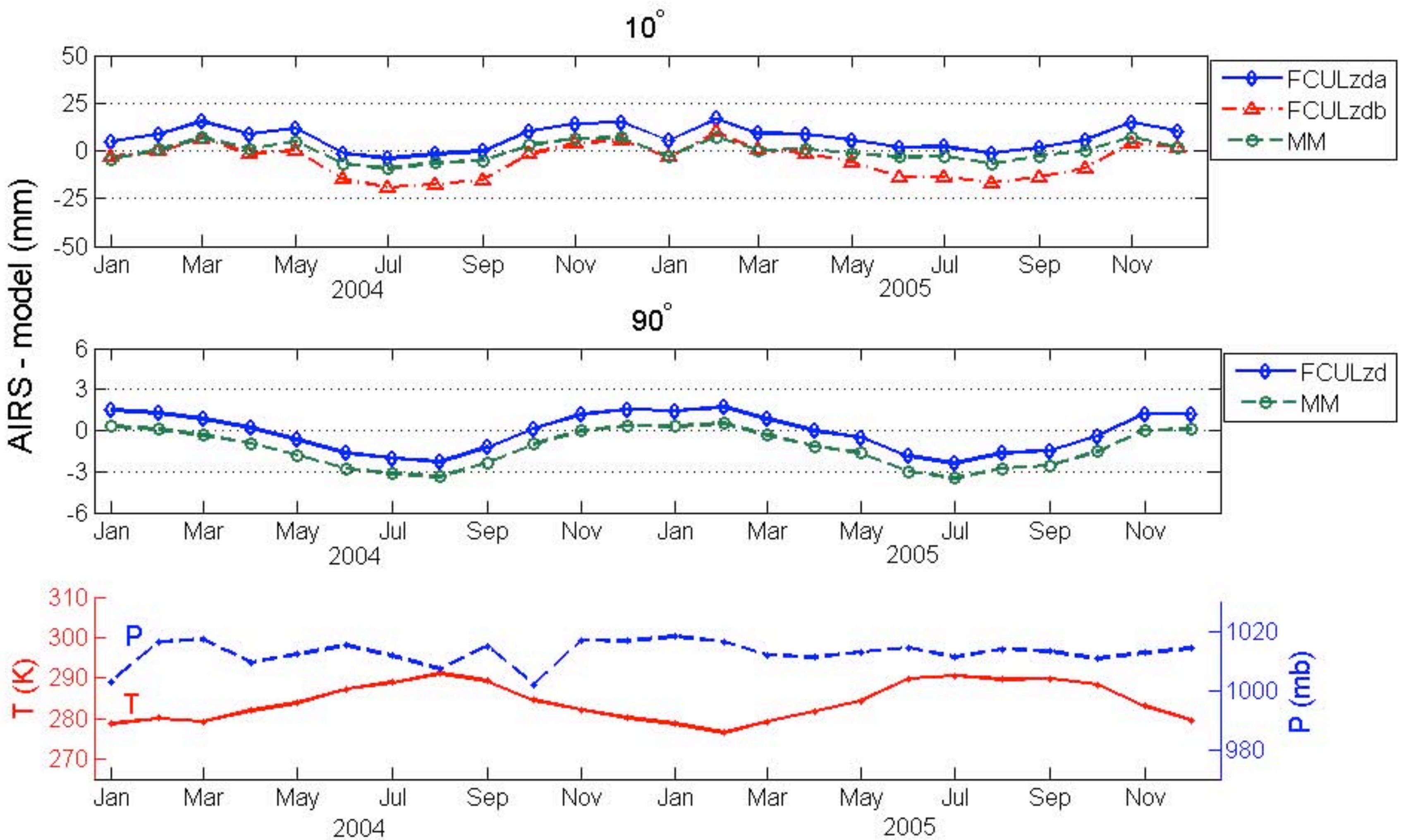
- Radiosonde data
- 180 stations
- 1998



- AIRS data
- 10 SLR stations
- 2004/2005

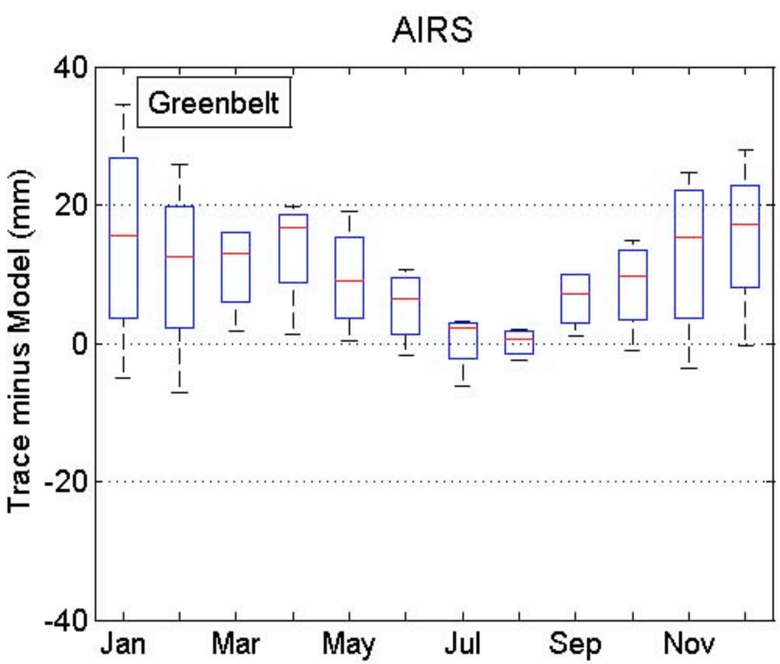
* *Mendes and Pavlis* [2004]

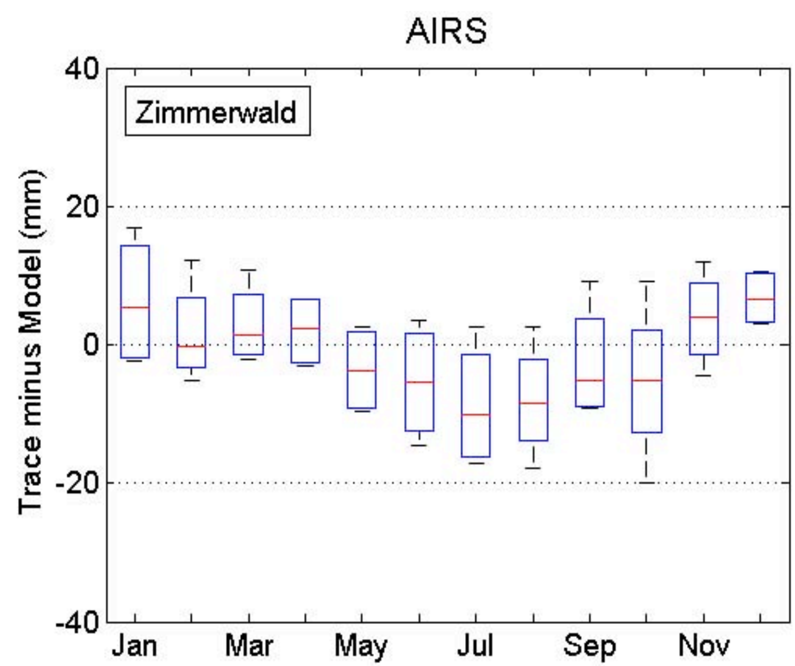
Delay differences at Herstmonceux, UK



Azimuthal delay differences

- Models assume spherical symmetry => no dependence on azimuth
- 8 azimuth angles: 0° - 360°, elevation angle: 10°
- Differences of up to 2.5 cm

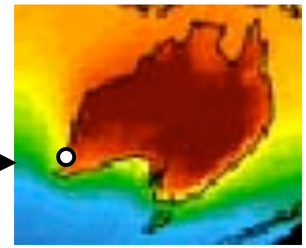




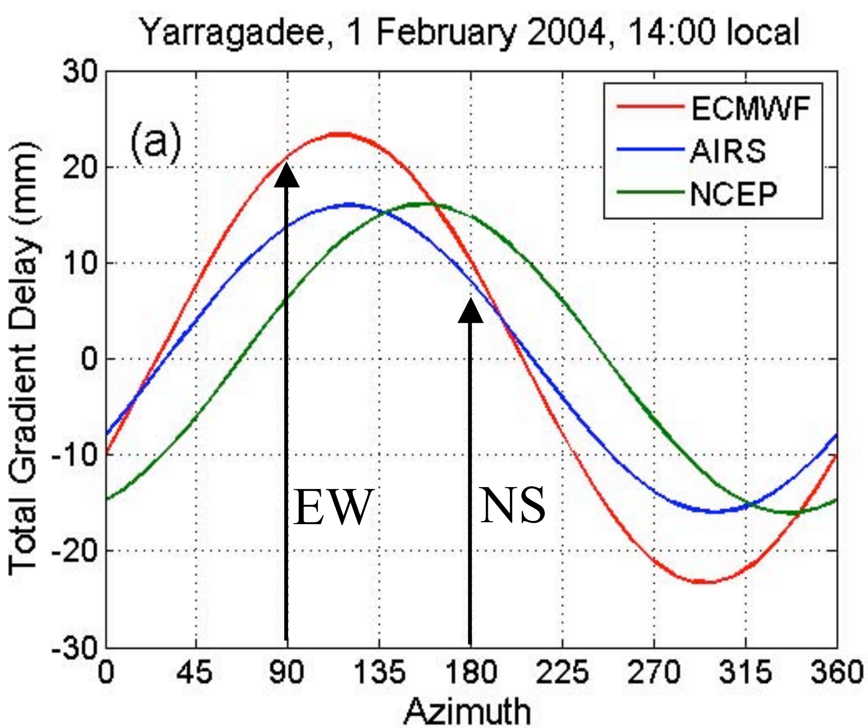
Temperature dependence

AIRS T_s

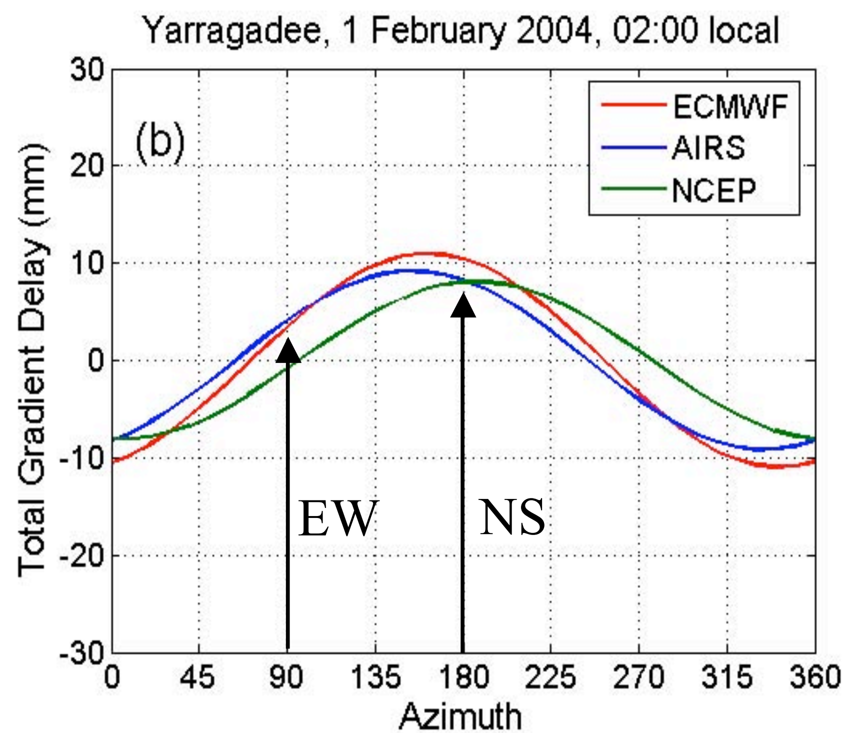
Yarragadee



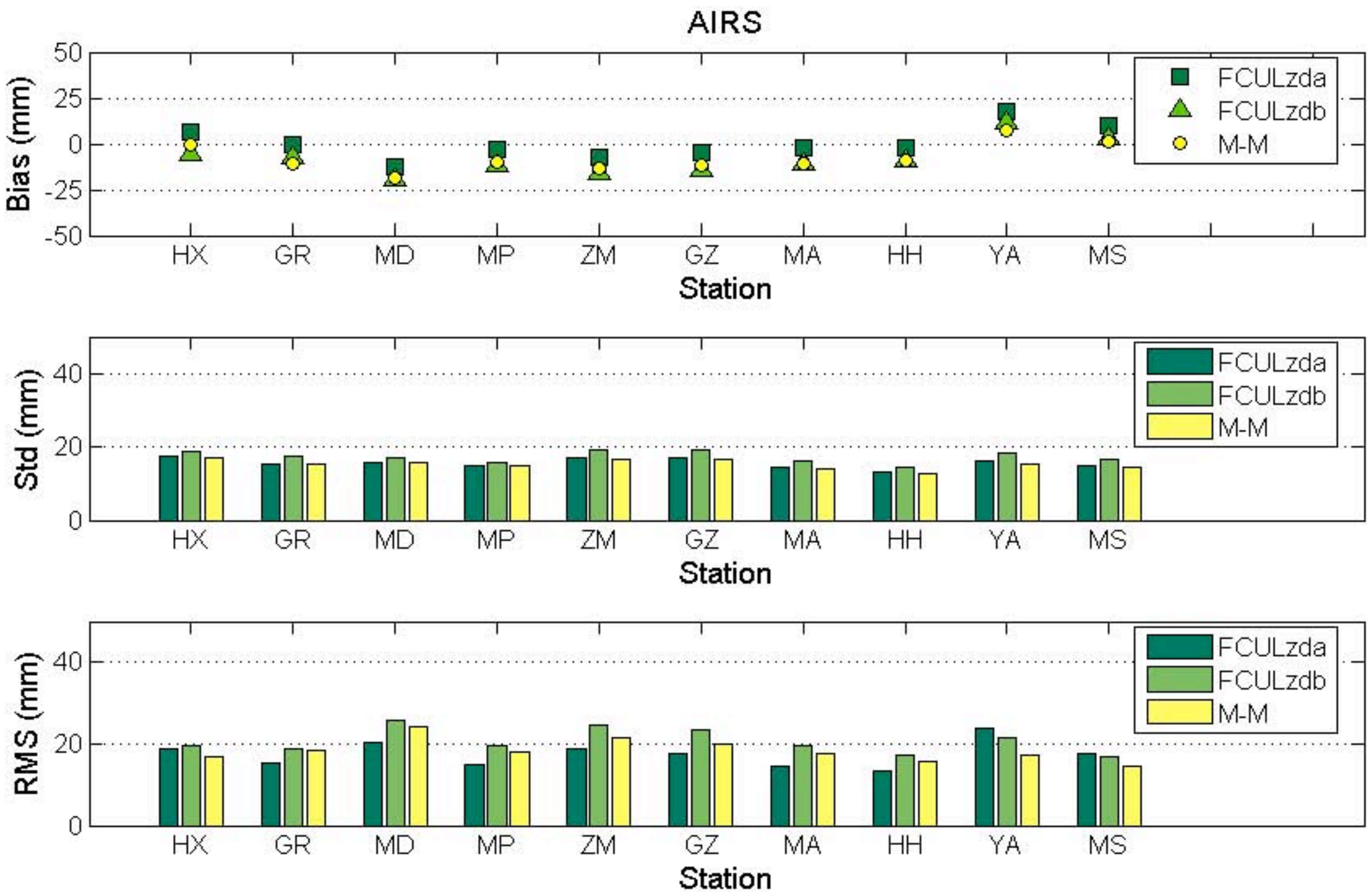
Day



Night

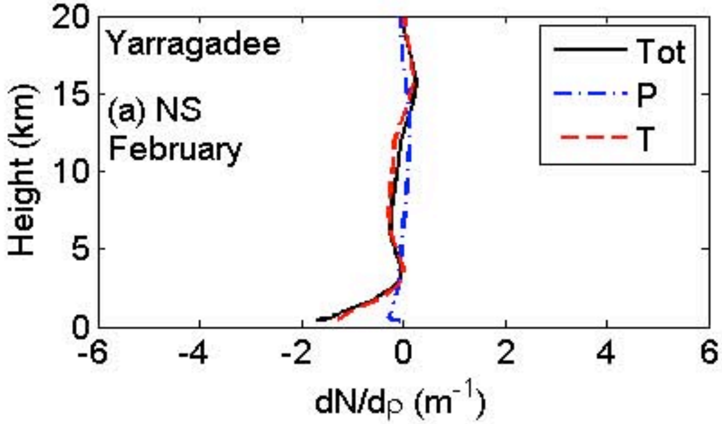


Model statistics summary

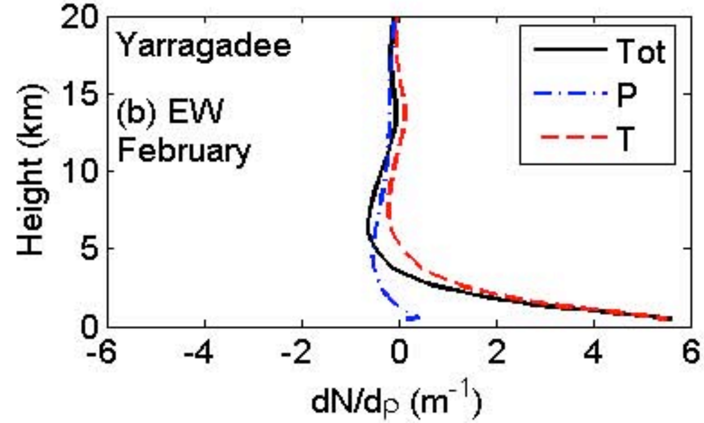


Gradient profiles - seasonal changes

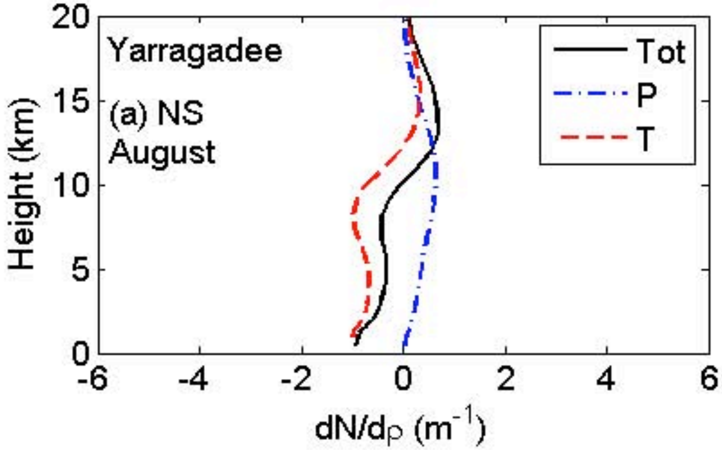
Summer



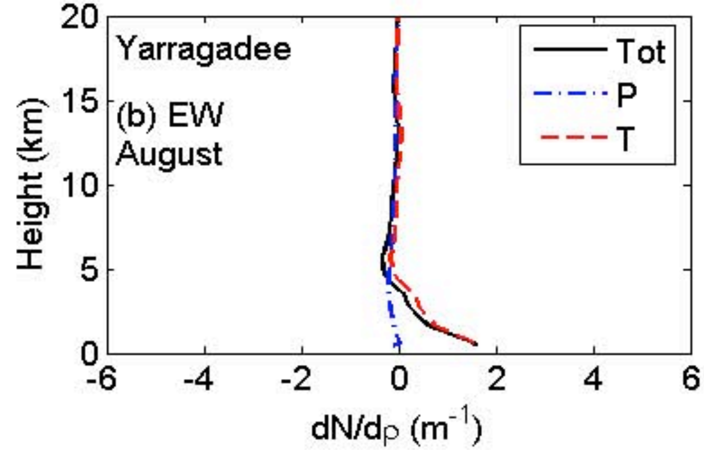
Summer



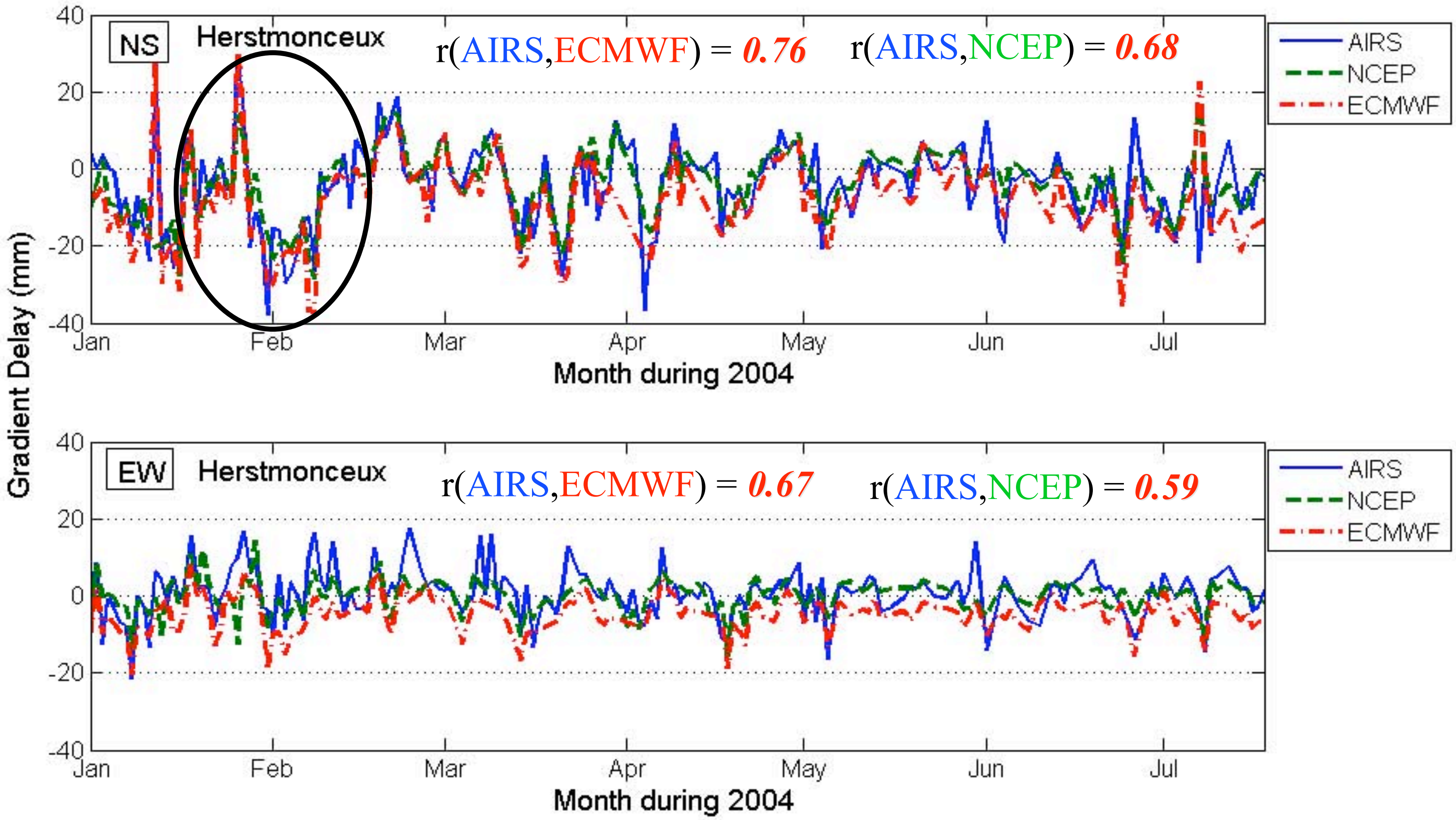
Winter



Winter



AIRS/ECMWF/NCEP gradient comparisons



Statistics between $AIRS_{grad}$ method and alternative methods for computing gradient delay

Method	Mean (mm)	Std (mm)	RMS (mm)
$AIRS_{3D\text{-}2D}$	5.1	3.0	5.9
MTT	2.1	19.3	21.0
ABG	-0.7	28.3	29.9

Atmospheric delay model errors

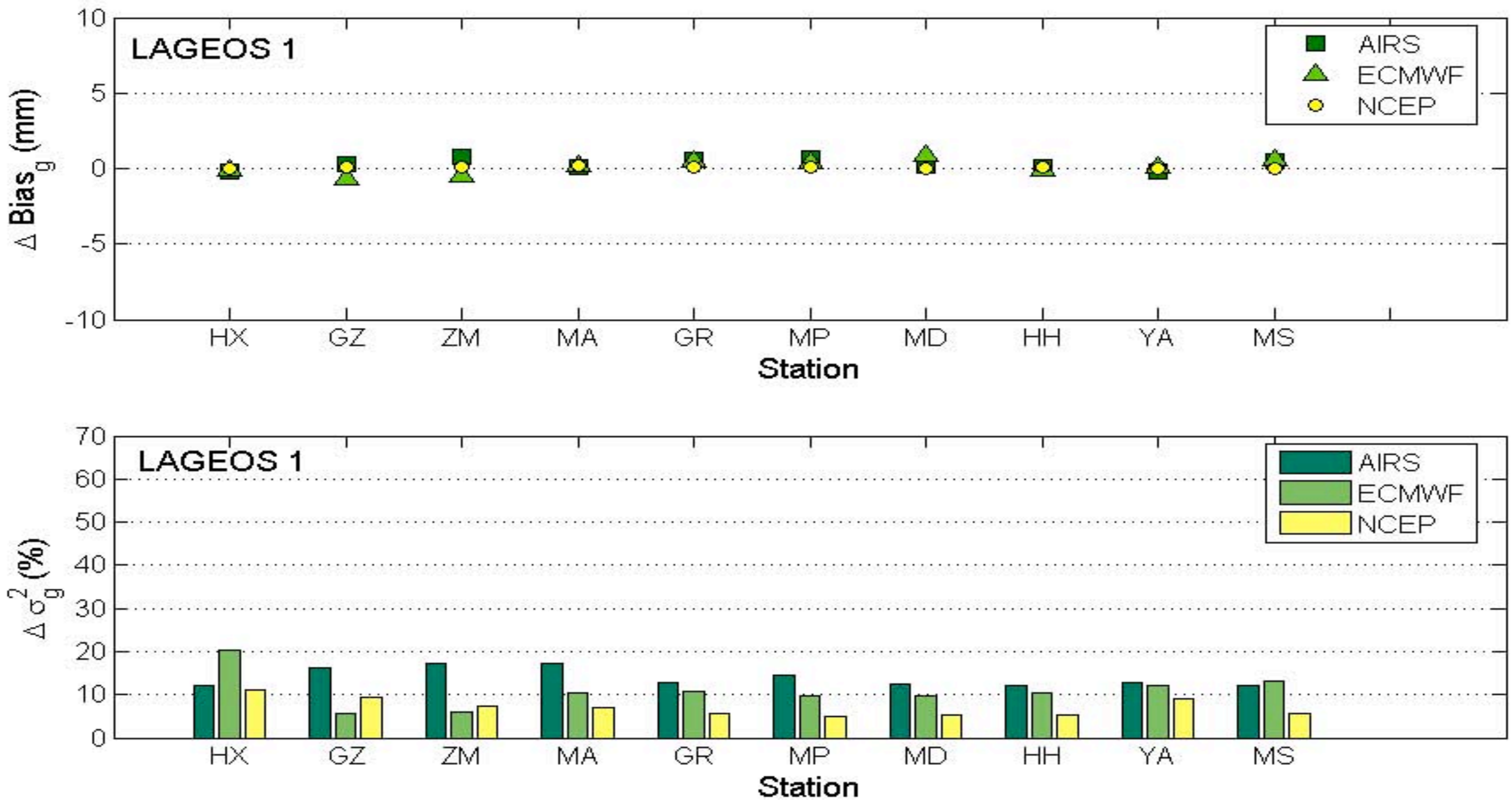
SOURCES OF MODEL ERROR	10°	90°
Horizontal Gradients – (NS+EW)	± 50 mm	± 1 mm
Azimuthal differences spherical symmetry approx.	± 25 mm	n/a
Zenith delay hydrostatic equilibrium approx.	± 20 mm	± 2 mm
Mapping function (T_s - dependence) Artificially large seasonal variations	± 5 mm	n/a
Diurnal differences (T_s - dependence)	± 5 mm	< 1 mm
Errors in surface measurements (T_s, P_s, e_o)	4.3 mm	< 1 mm

SLR Range Residuals

- Real SLR data from LAGEOS 1 and 2 (2004 - 2006)
- 10 Core SLR stations (47,664 observations)
- Meteo grid data preprocessing
  - Temporal interpolation to observation time
  - Surface met. values at station (MET3)
- Residuals = Range (obs) – Range (calcs.)
- Minimizing variance of residuals

  => Improve orbit determination

  => Improve accuracy of ITRF
- Atmospheric correction 1 = FCULzda + gradients
- Atmospheric correction 2 = RT_{2d} + gradients
- Atmospheric correction 3 = RT_{3d}



Gradient-corrected

$R = O - C$

$R_g = O - (C + RT_{grad})$

RT_{grad} – ray trace gradient correction

$$\Delta Bias_g = |\overline{R}| - |\overline{R_g}|$$

$$\Delta\sigma^2{}_g = \frac{\sigma^2(R) - \sigma^2(R_g)}{\sigma^2(R)} \cdot 100$$

Residual Statistics Summary

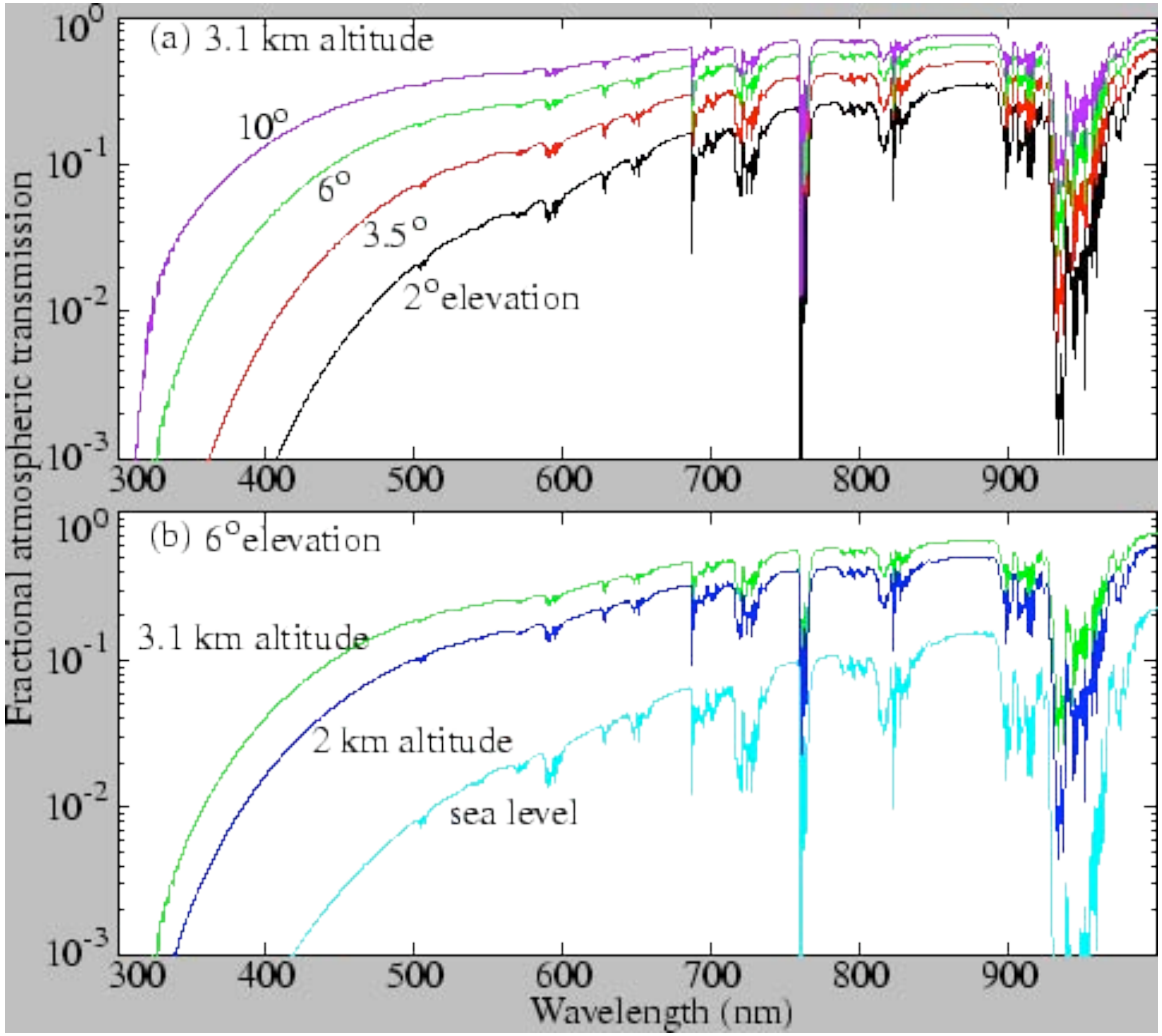
Method	ΔBias (mm)	$\Delta\sigma^2$ (%)
AIRS		
RT_{grad}	0.3 ± 0.3	14.0
RT_{3d}	0.9 ± 1.1	24.8
ECMWF		
RT_{grad}	0.1 ± 0.5	10.8
RT_{3d}	0.6 ± 1.2	22.5
NCEP		
RT_{grad}	0.1 ± 0.1	7.1
RT_{3d}	n/a	n/a

Summary

- Refraction corrections limiting factor in SLR accuracy
- Developed robust 2D and 3D ray tracing program with AIRS/ECMWF/NCEP data
- Delay models assumptions are unreasonable
  - Delay models neglect horizontal refractivity gradients
- Ray tracing (2D + gradients) minimizes residual variance
- 3D Ray tracing however
  - brings further improvement
  - it is a more efficient method
- Unification of data sources
- Automated ray tracing for future refraction corrections

Conclusions

- Laid groundwork for future 3D refractivity corrections
- Minimizing variation of range residuals:
  => Precise orbit determination
  => More accurate SLR station position coordinates
  => More accurate and stable ITRF (0.5 ppb ~3 mm)
  => Improves understanding and knowledge of Earth properties
    - Sea-level rise
    - Post-glacial rebound
    - Plate tectonics
    - Earth orientation parameters
    - Gravity field studies
- Application of ray tracing corrections on SLR products:
  – NASA Proposal for an operational product for all SLR data



(a) 3.1 km altitude
10°
6°
3.5°
2°elevation
(b) 6°elevation
3.1 km altitude
2 km altitude
sea level
Fractional atmospheric transmission
Wavelength (nm)

Prediction Format Study Group

- Status of CPF implementation
  - Several stations still have not converted to CPFs
  - Recommend discontinuing TIVs by end of 2007
- Status of manual and sample code
  - Bug fix sample code v1.01a released
  - Manual is being corrected and updated
  - Sample code being updated for transponders

Prediction Format Study Group

- LRO predictions
  - To be produced by Goddard Flight Dynamics Facility (FDF)
  - Available for testing in June, 2007
  - Will include light-travel-time-corrected outbound le and no relativistic corrections, due to loose accuracy requirements (several msec in range)

Consolidate Laser Ranging Data (CRD) Format

Changes since Canberra...

Introduction to CRD

- Needed for
  - Additional precision and info for one-way ranging
  - Eliminate redundancy for high-rep-rate fullrate data
- Design similar to CPF
  - Building block structure
  - Expandable and extensible
  - Partially free format
  - Includes normal point, fullrate, and sampled engineering data

Format Changes

- Format more hierarchical w/ single-purpose records
  - Impact when there are several passes/file
  - Compatible with XML
- Added configuration section
  - Compatible with EDF
  - Allows more complete description of pass
- Added skew, kurtosis, and peak-mean
- Rewriting file naming conventions
- PDF version on ILRS web site

New Document Sections

- Configuration Records
- Sample files
  - Based on converter from old format
  - Includes 2-color normal point file
- Resources: web addresses for
  - old and new formats,
  - Satellite and station name lists
- Common Abbreviations

Samples - I
2-Color Normal Points

```
H1 CRD  1 2007  3 20 14
H2 ZIMMERWALD 7810 68  1 7
H3 LAGEOS1     7603901 1155     8820 0
H4  1 2006 12 30  7 35 34 2006 12 30  8 12 29  0 0 0 0 1 0 2
C0 0 846.000 std1
C0 0 423.000 std2
60 std1 9 0
60 std2 9 1
11 27334.1080890 0.051571851861 std1 2  120     36     154.0 -1.000 -1.000 -1.0 0.0
20 27334.1080890  923.30 275.40   43
40 27334.1080890 0 std1       -1        -1 0.000 113069.0 0.0 138.0 -1.000 -1.000 -1.0 2 2
11 27343.5080895 0.051405458691 std2 2  120     28      79.0 -1.000 -1.000 -1.0 0.0
...
11 29549.5080897 0.051535764981 std2 2  120     14      87.0 -1.000 -1.000 -1.0 0.0
50 std1 165.0 -1.000 -1.000 -1.0 0
50 std2 78.0 -1.000 -1.000 -1.0 0
H8
H9
```

Sample - II
Configuration Records

```
C0 0 532.0 std1 slrd las1 tim1 lro
C1 0  las1 Nd-Yag 1064.0 10.0 100 200 20 1
C2 0 slrd MCP 532.0 8 1300 1 TTL 10 1.0 50 10 none
C3 0 tim1 TAC na MLRS na 0
C4 0 lro 100 5  325 8 12345678m1 0 1
```

Samples - 3
Multiple Sessions per Station File

Preferred method

```
H1 H2 H3 H4 ... H8
     H3 H4 ... H8
     ...
     H3 H4 ... H8 H9
```

Acceptable, but not preferred, method

```
H1 H2 H3 H4 ... H8
H1 H2 H3 H4 ... H8
...
H1 H2 H3 H4 ... H8 H9
```

Questions to ponder

- How often should new angle records be written? 0.1°? .001°?
- Should SCH/SCI be required even with configuration record? Until full adoption of CRD?
- Is a software configuration record needed? How would it be structured?
- Station names? Start by using 4-character “code”?
- Can refraction data and center of mass in be optional for fullrate?

Next...

- DF&P WG and GB approval of format
- Pilot conversion projects
  - Converters to generate old format from CRD
  - Converters between CRD and XML
  - Implement CRD at MLRS and Stromlo (by Fall meeting)
  - Provide format to LRO
- Only additional format changes:
  - From results of pilot projects, or
  - Needs for more configuration information

Thanks!

- Jan McGarry
- Chris Moore
- Kalvis Salminsh
- Carey Noll
- Julie Horvath
- Many others whose input was priceless

BACKUP SLIDES

“Header” Records

- H1 – Format header
- H2 – Station header
- H3 – Target header
- H4 – Session/Pass header
- H8 – Session/Pass footer
- H9 – End of File footer

“Configuration” Records

- C0 – System
- C1 – Laser
- C2 – Detector
- C3 – Timing
- C4 – Transponder

“Data” Records

- 10 – Range (FRD, QLK)
- 11 – Range (NPT)
- 12 – Range Supplement
- 20 – Meteorology
- 21 – Meteorological Supplement
- 30 – Pointing Angles
- 40 – Session/Pass Statistical

“Data” Records - II

- 50 – Calibration “normal point”
- 60 – Compatibility (for SCH/SCI)
- 90-99 – User defined
- 00 – Comments