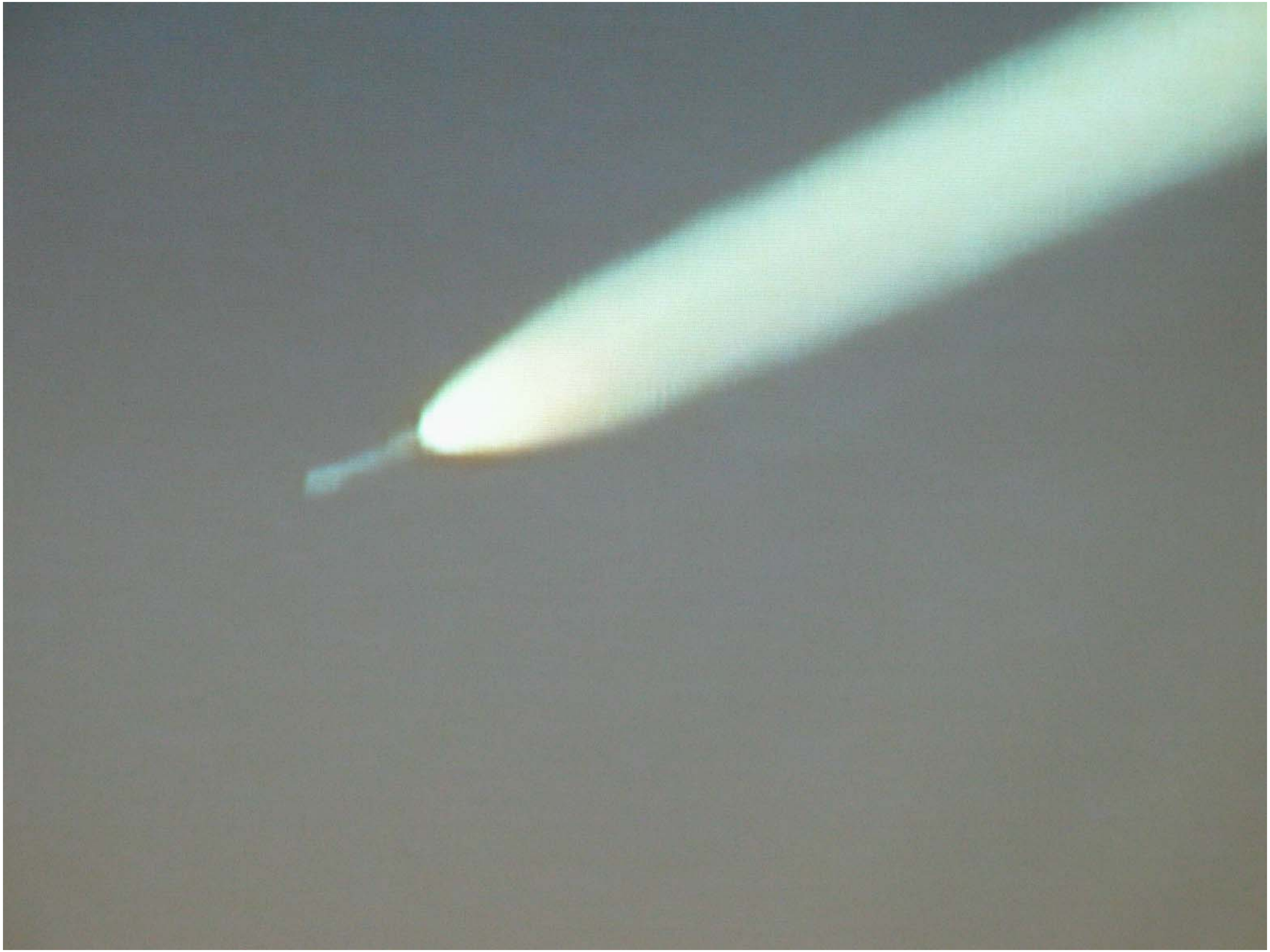

Thank you!
Hsin Chu, May 2004

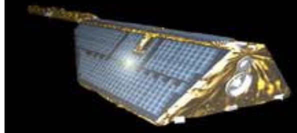
Launch of FORMOSAT-2 May 20, 2004

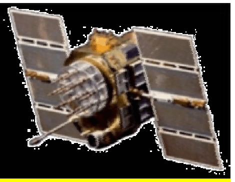

TAURUS/ROCSAT-2 Mission
May 20, 2004
Live Launch Coverage
Will Begin at 10:35 AM PDT



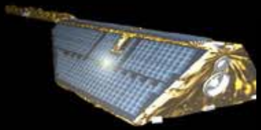

中華衛星二號發射活動
ROCSAT-2 LAUNCH CAMPAIGN

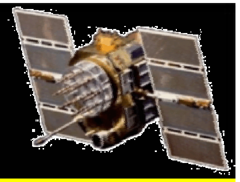

We wish Formosat-3/COSMIC
great success!
NSPO





My way to this summer camp started here



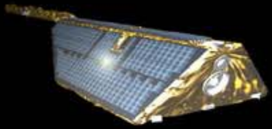


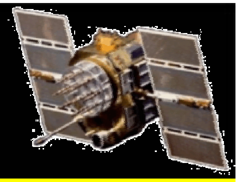

Nordmeer
Nordsee
Lappland
Stockholm
ST.-PETERSBURG
Helsinki
Tallinn
LONDON
PARIS
Prag
Wien
Budapest
Kiew
Charkiv
Odesa
Bukarest
Belgrad
Rom
Neapel
Marseilles
Barcelona
Madrid
Algiers
Tunis
Tripolis
ISTANBUL
Ankara
Athen
Izmir
Damaskus
Amman
Bagdad
TEHERAN
Baku
Tiflis
Kazan'
Samara
Saratov
Rostov n.D.
München
Hamburg
Stettin
Rostock
Kopen-hagen
Oslo
Bergen
Trondheim
Murmansk
Arhangel'sk
Dublin
Edinburgh
Großbritannien
Mittelländisches Meer
Schwarzes Meer
Kaspisches Meer
Weißes Meer
Ostsee
Finn. Meerbusen
Bottnischer Meerbusen
Karpaten
Adriatisches Meer
Tyrrhenisches Meer
Jonisches Meer
Golf von Biscaya
Lindenberg near Berlin


Meteorological observatory Lindenberg
(1905-2005), this year 100 years old
Old winch house (renovated)

Weather kite (~10,000 m Altitude , 1910, world record)

Today one of the most unique observatories worldwide!

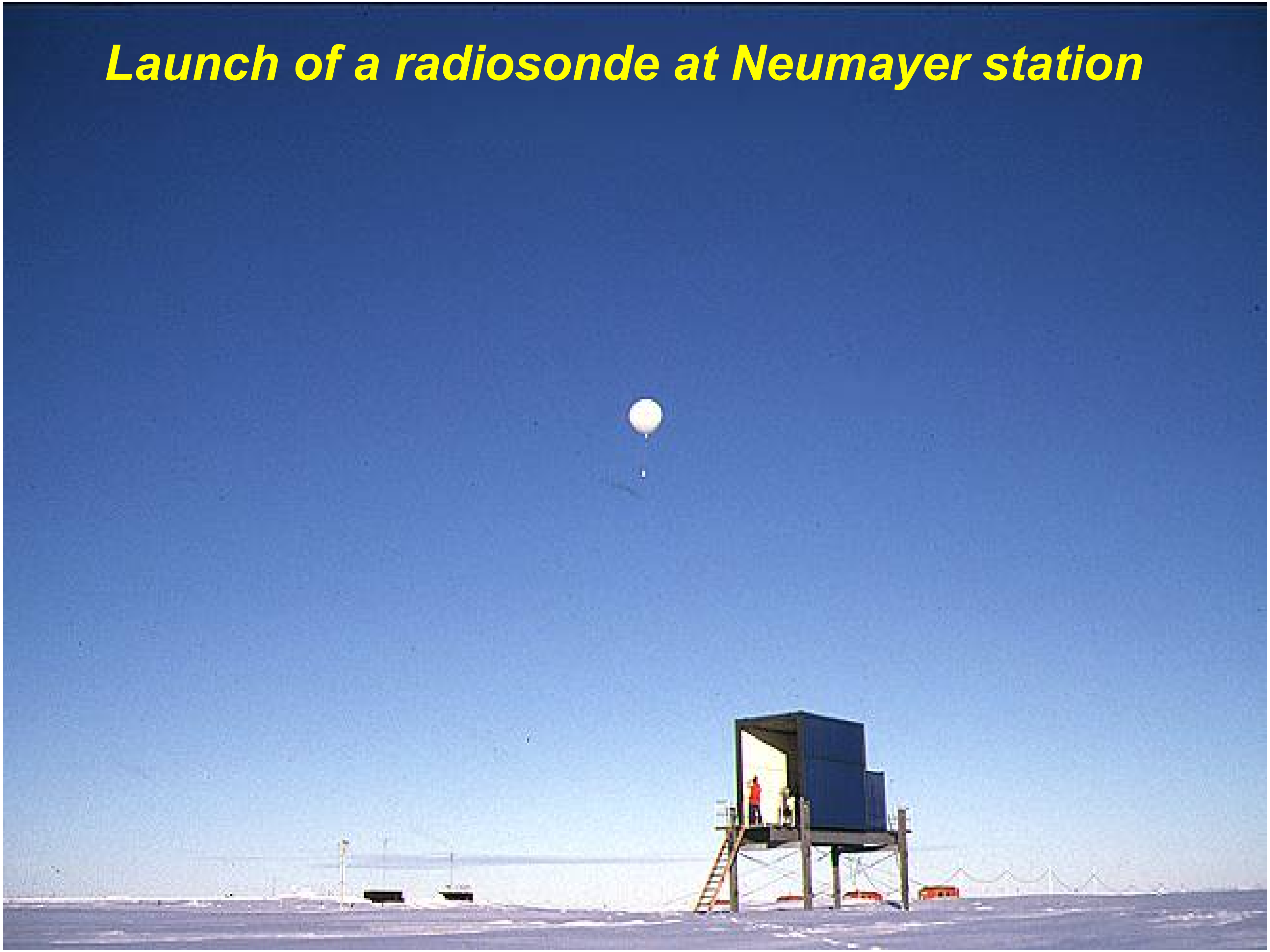


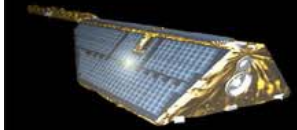


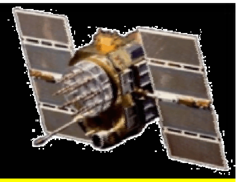
Lindenberg was also one center of the German Antarctic research

South pole: 2,151 km; A great year

Launch of a radiosonde at Neumayer station



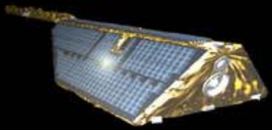


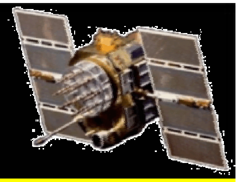


And
no global coverage

The way out:
satellites

Satellite receiving station Neustrelitz, Germany



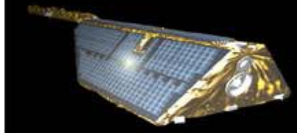


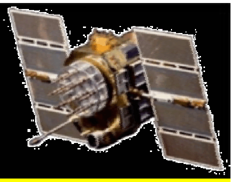
It seems to be interesting

and

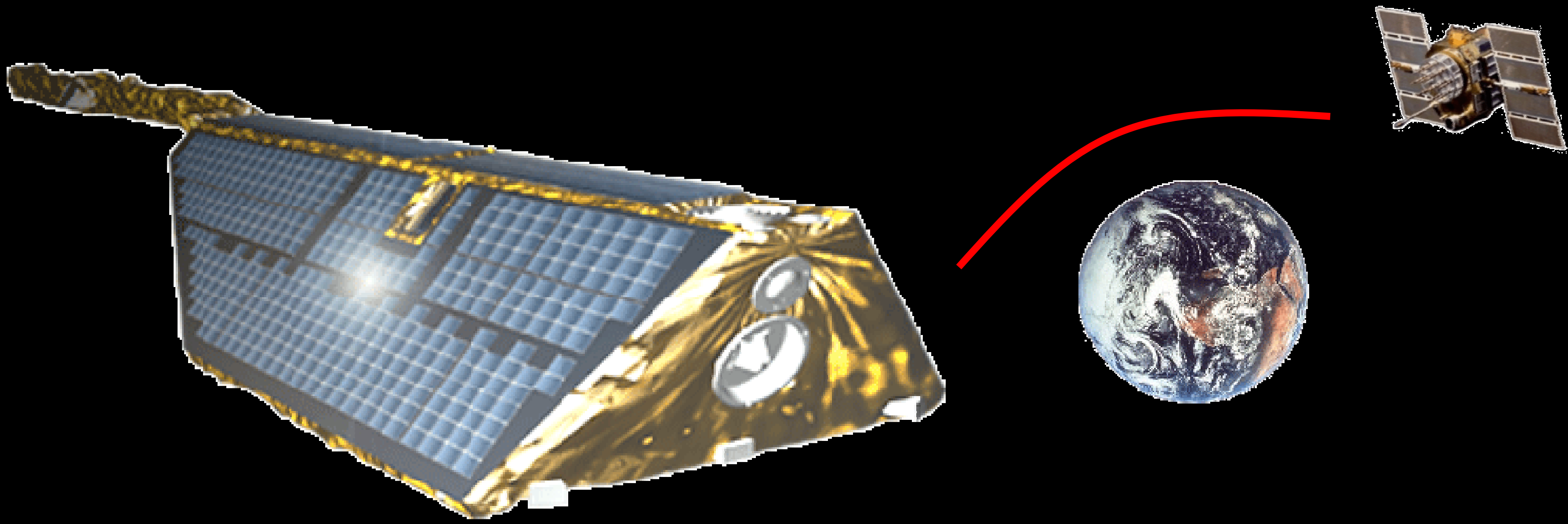
is in principle the same as launching radiosondes

And: a bit more comfortable





Here I am!



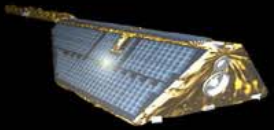
CHAMP: Scientific results

Jens Wickert

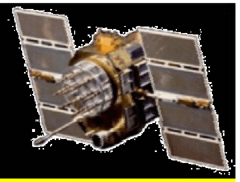
With contributions from:

C.O. Ao, G. Beyerle, A. Gobiet, U. Foelsche, G. Hajj, S.B. Healy, S. Heise, A. Helm, N. Jakowski, R. König, B. Kuo, H. Lühr, V. Ratnam, C. Stolle, Ch. Reigber, Ch. Rocken, T.Schmidt, W.B. Schreiner

GFZ POTSDAM



Content



1) The CHAMP mission

2) GPS radio occultation with CHAMP

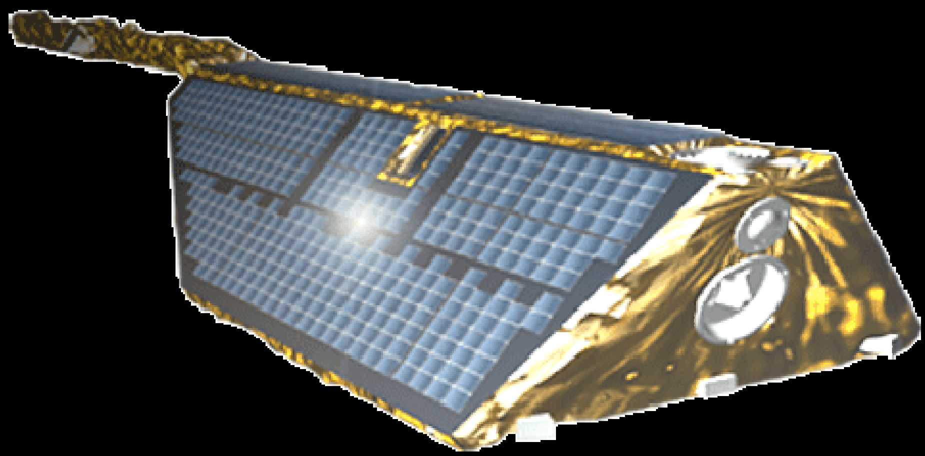
3) Data analysis

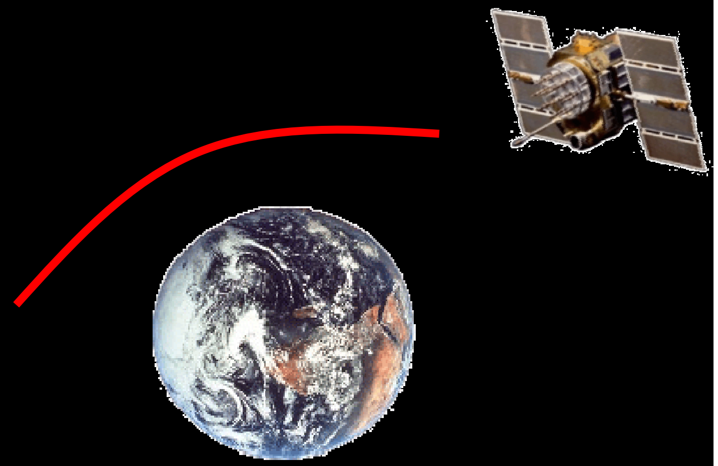
4) Validation

5) Applications

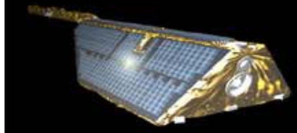
6) Ionosphere

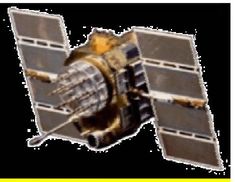
7) Summary and Outlook





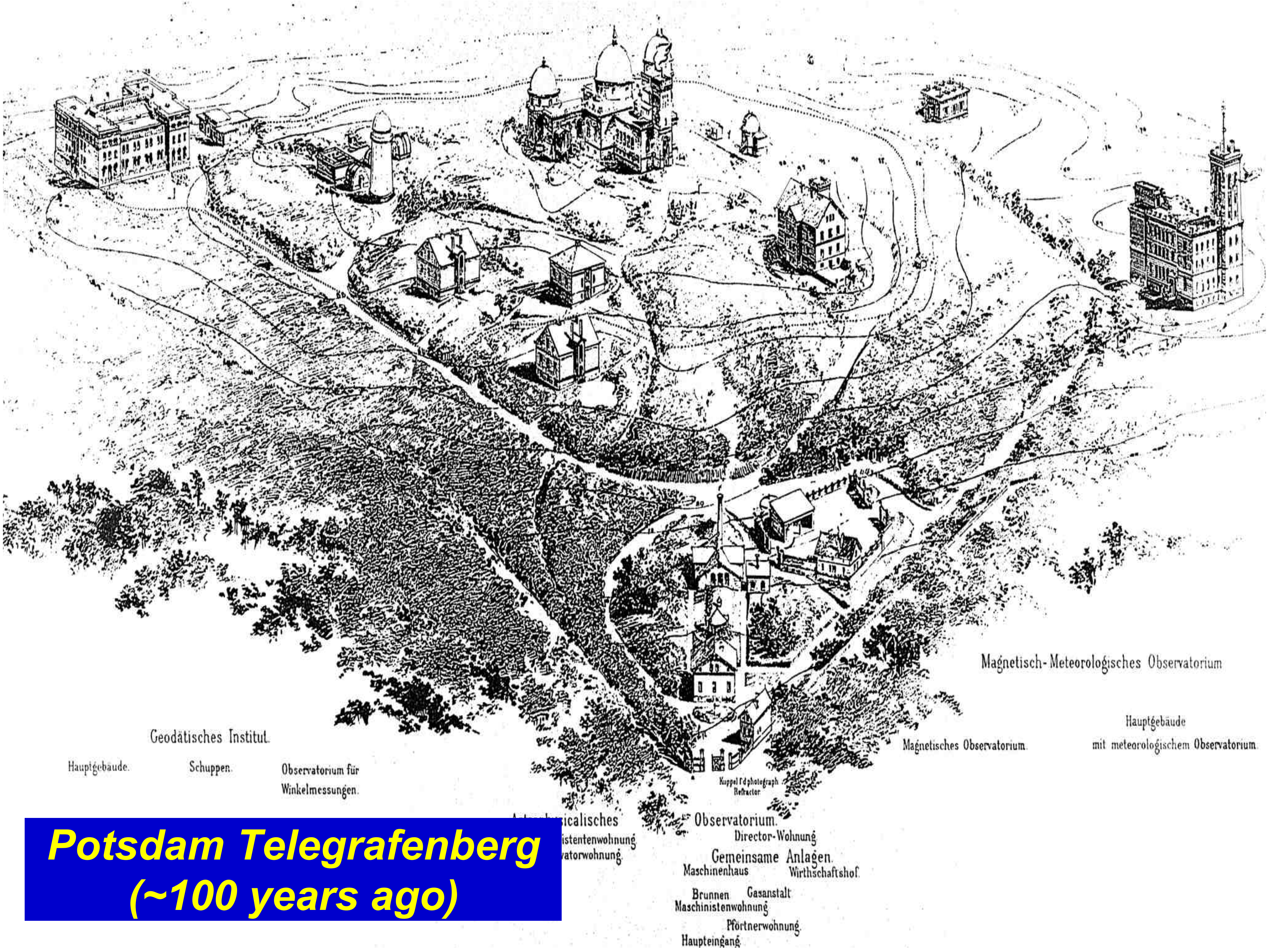
The CHAMP mission





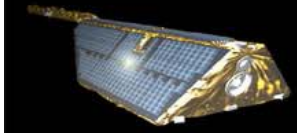
Where does the idea from CHAMP come from?


Potsdam Telegrafenberg

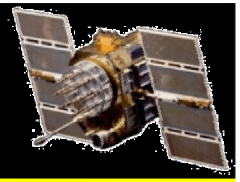


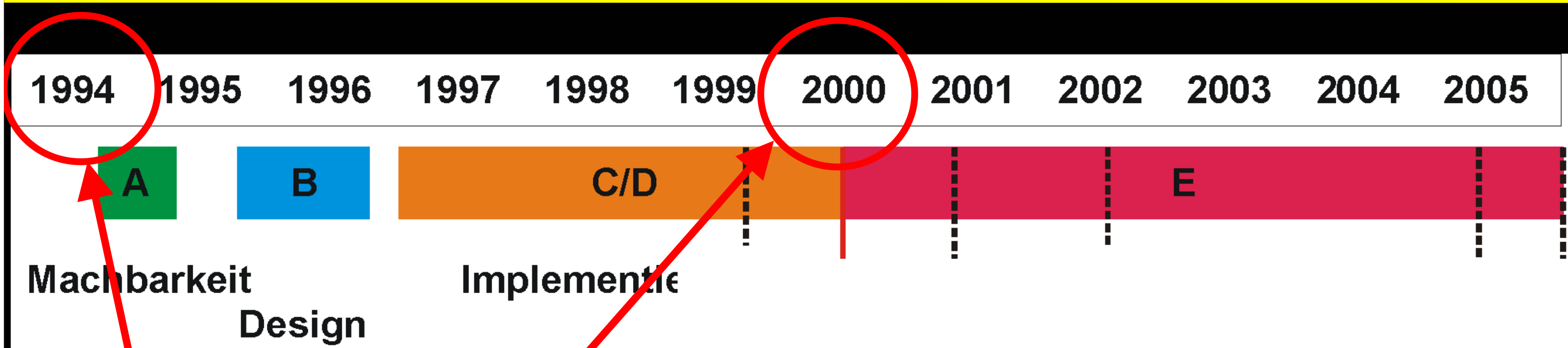
Potsdam Telegrafenberg
(~100 years ago)

It is a long way before one can report about scientific results!
Some Impressions



The CHAMP project: schedule





6 years from begin phase A to the launch! Nevertheless quite fast

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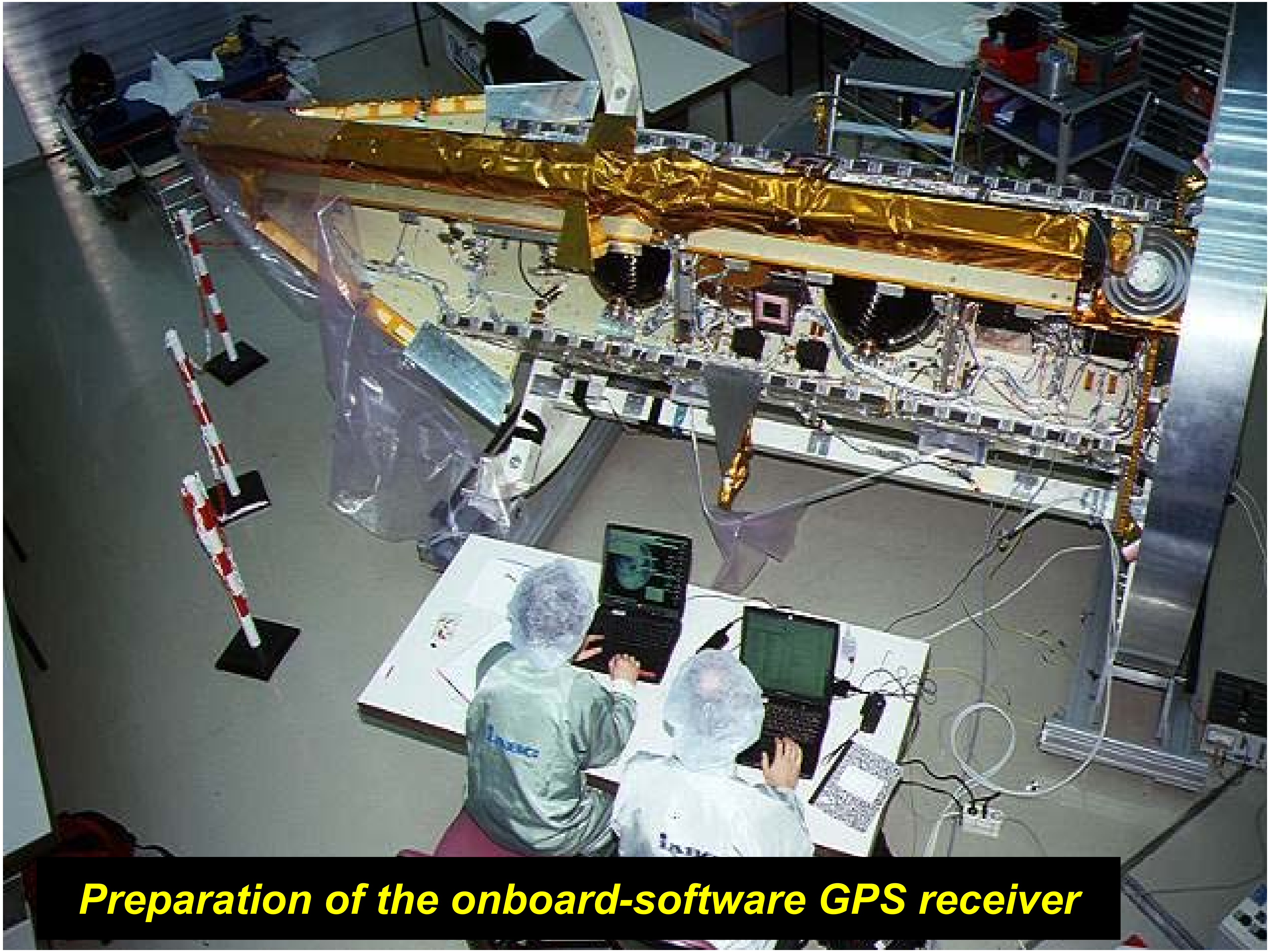
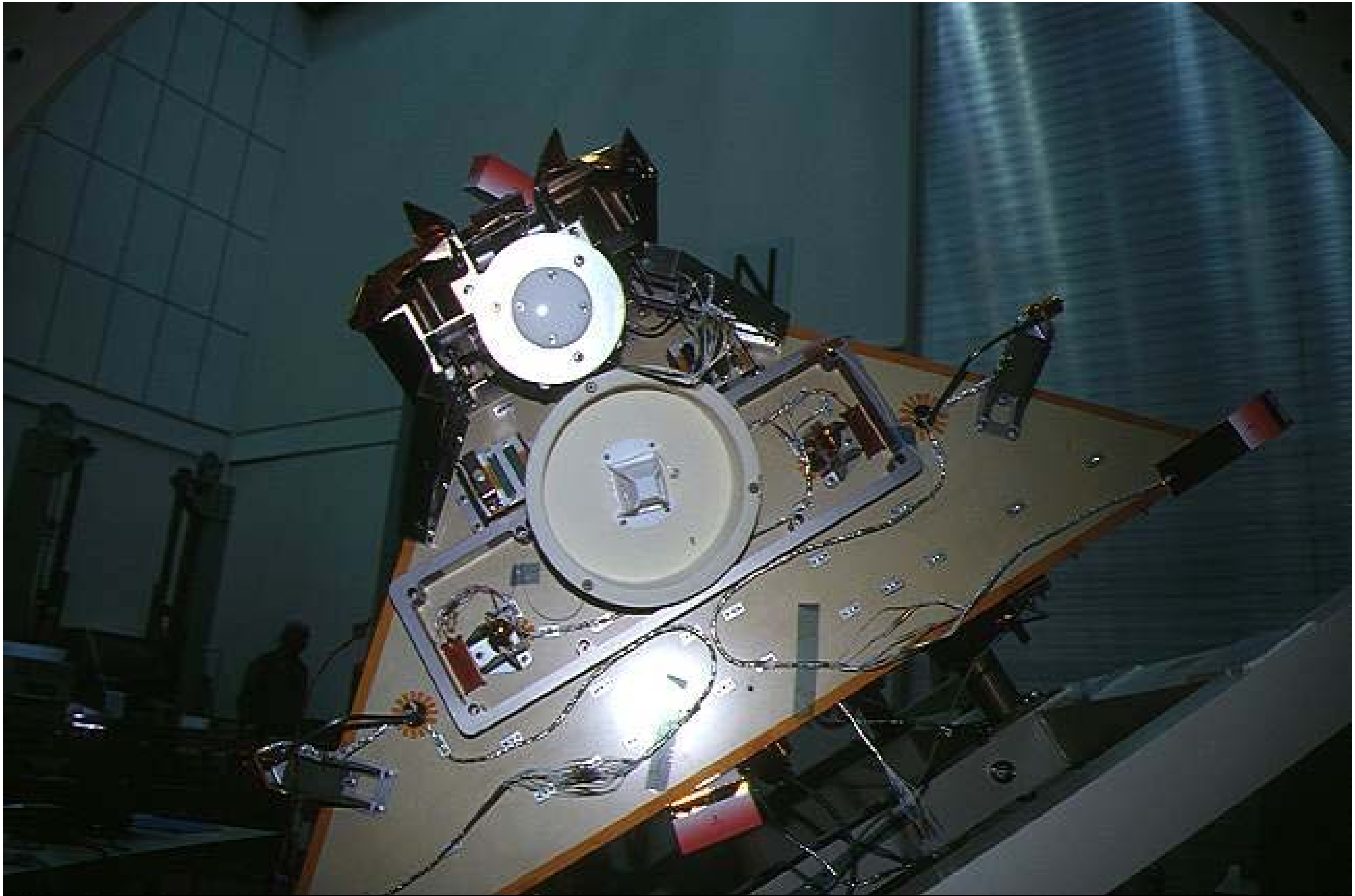
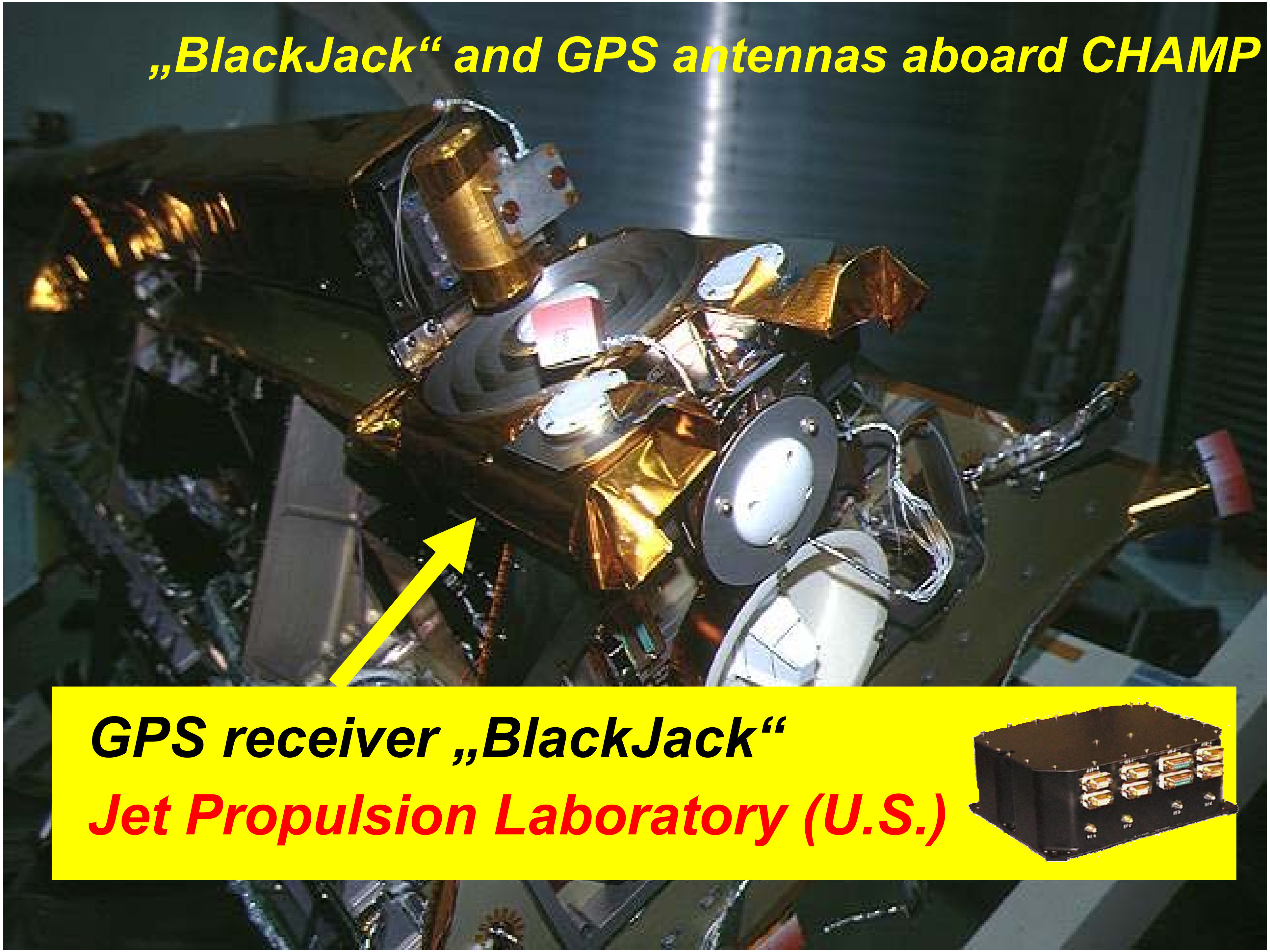
Construction and test



Preparation of the onboard-software GPS receiver



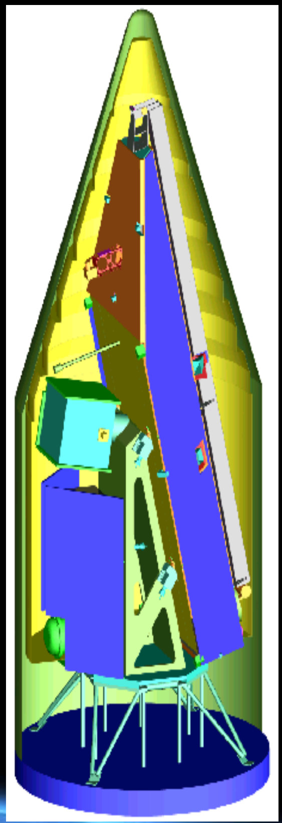
Occultation antenna

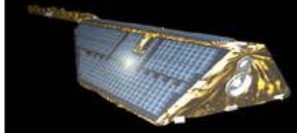

„BlackJack“ and GPS antennas aboard CHAMP
GPS receiver „BlackJack“
Jet Propulsion Laboratory (U.S.)

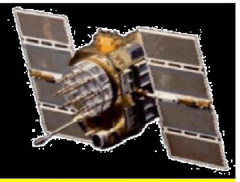

Naming cerenomy
Nov 13, 1998
11/13/1998

The Launch:
July 16, 2000

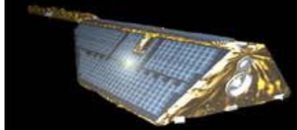
COSMOS-3B launcher Plesetzk



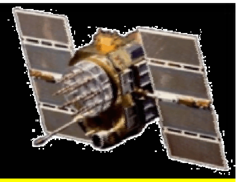


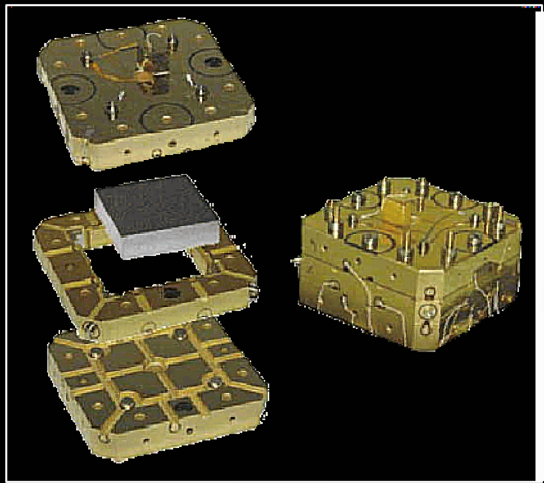


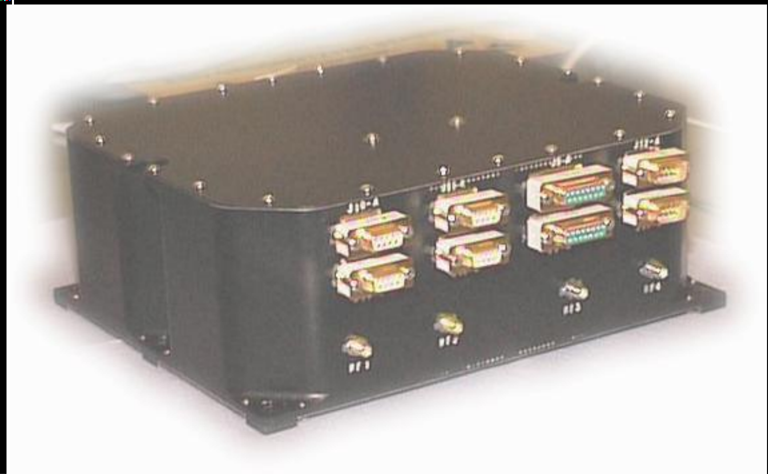
Instruments and experiments aboard CHAMP

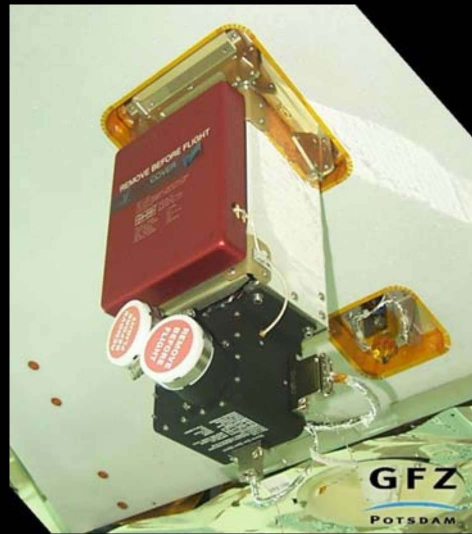


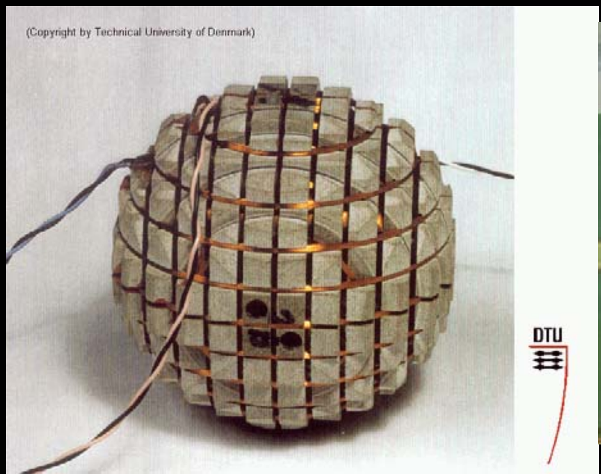
The instruments aboard CHAMP

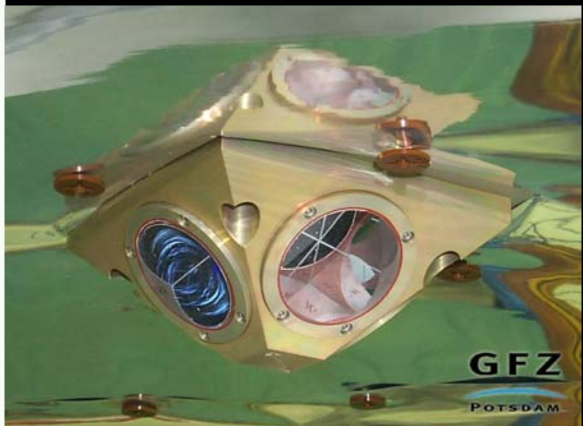


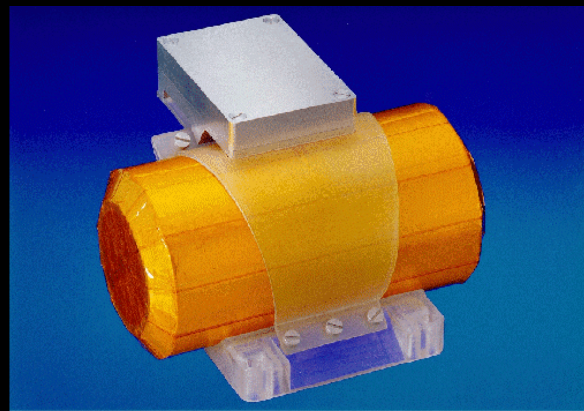






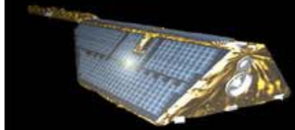




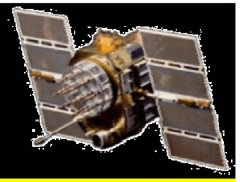


Overhauser Magnetometer

leti



Main mission goal: gravity field

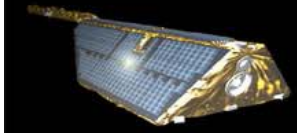


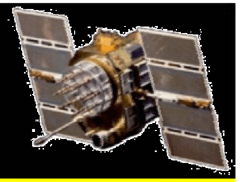
Real orbit not “smooth”

=

Shape of “Bumpy” orbit is related to variations of the gravity force

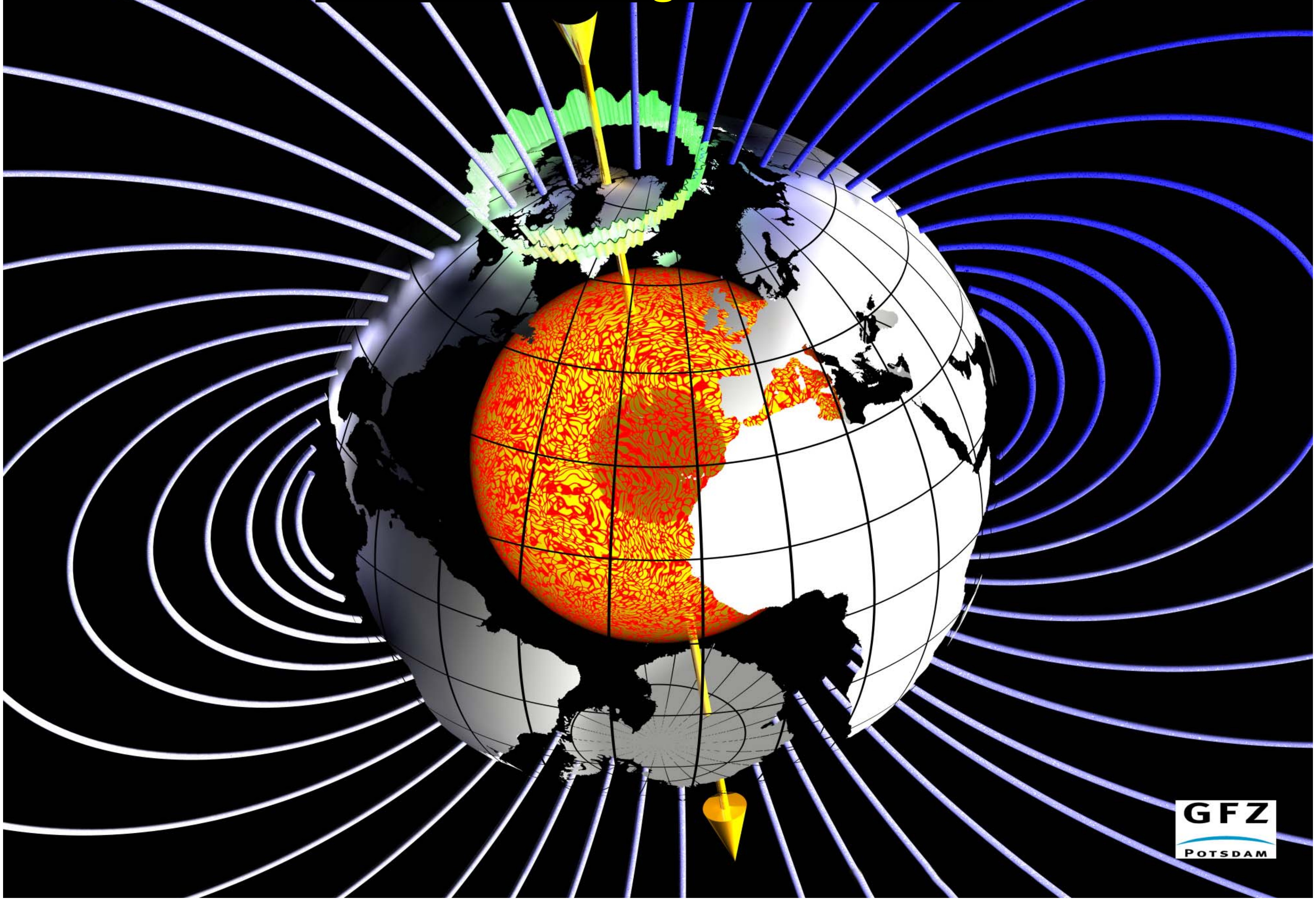
GPS plays an mportant role thereby





CHAMP: Magnetic field

Earth's magnetic field



Example: Ocean currents(here: Tides)

Relevance for climate studies

Proof only was possible due to the accuracy of the CHAMP instrumentation (2nT at 50.000 nT field strength)

Provided by H. Lühr, S.Maus

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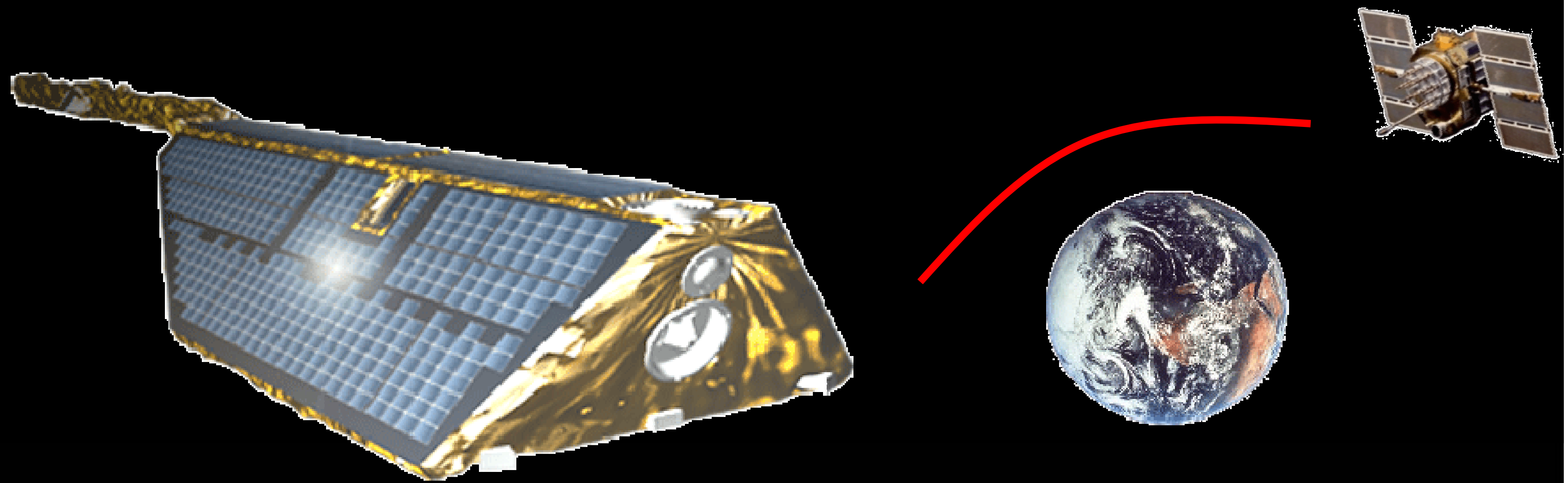

GPS radio occultation with CHAMP

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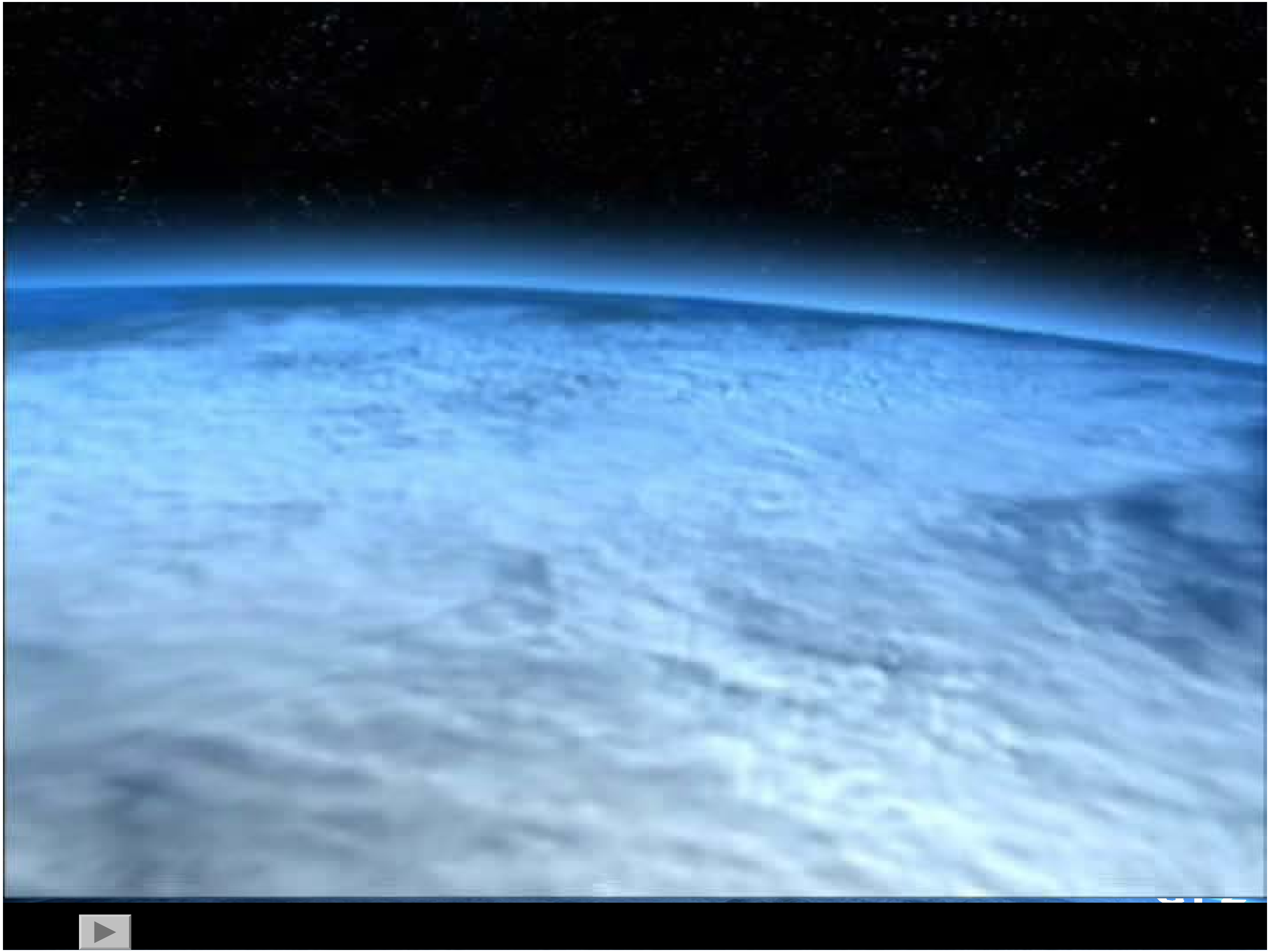
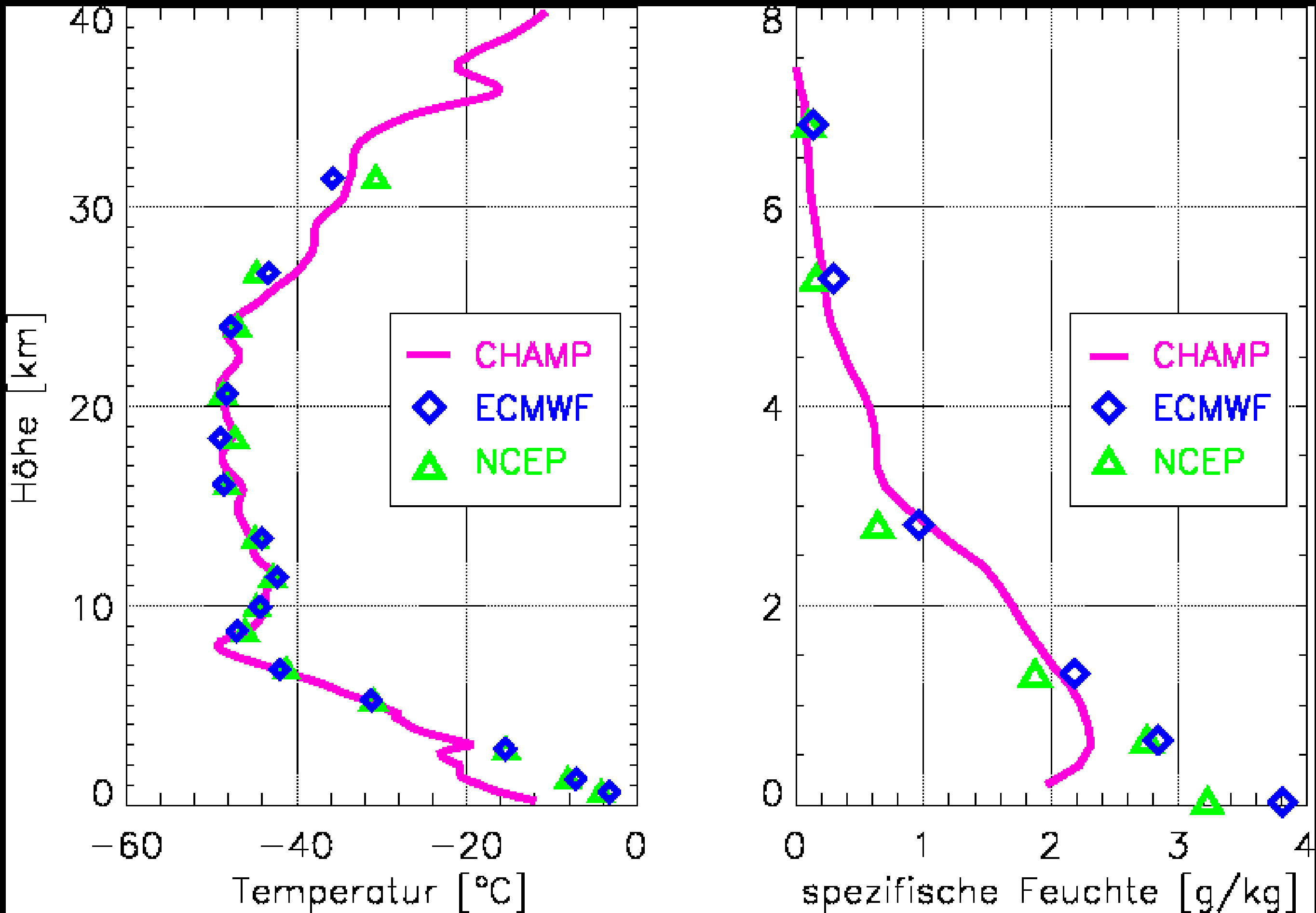
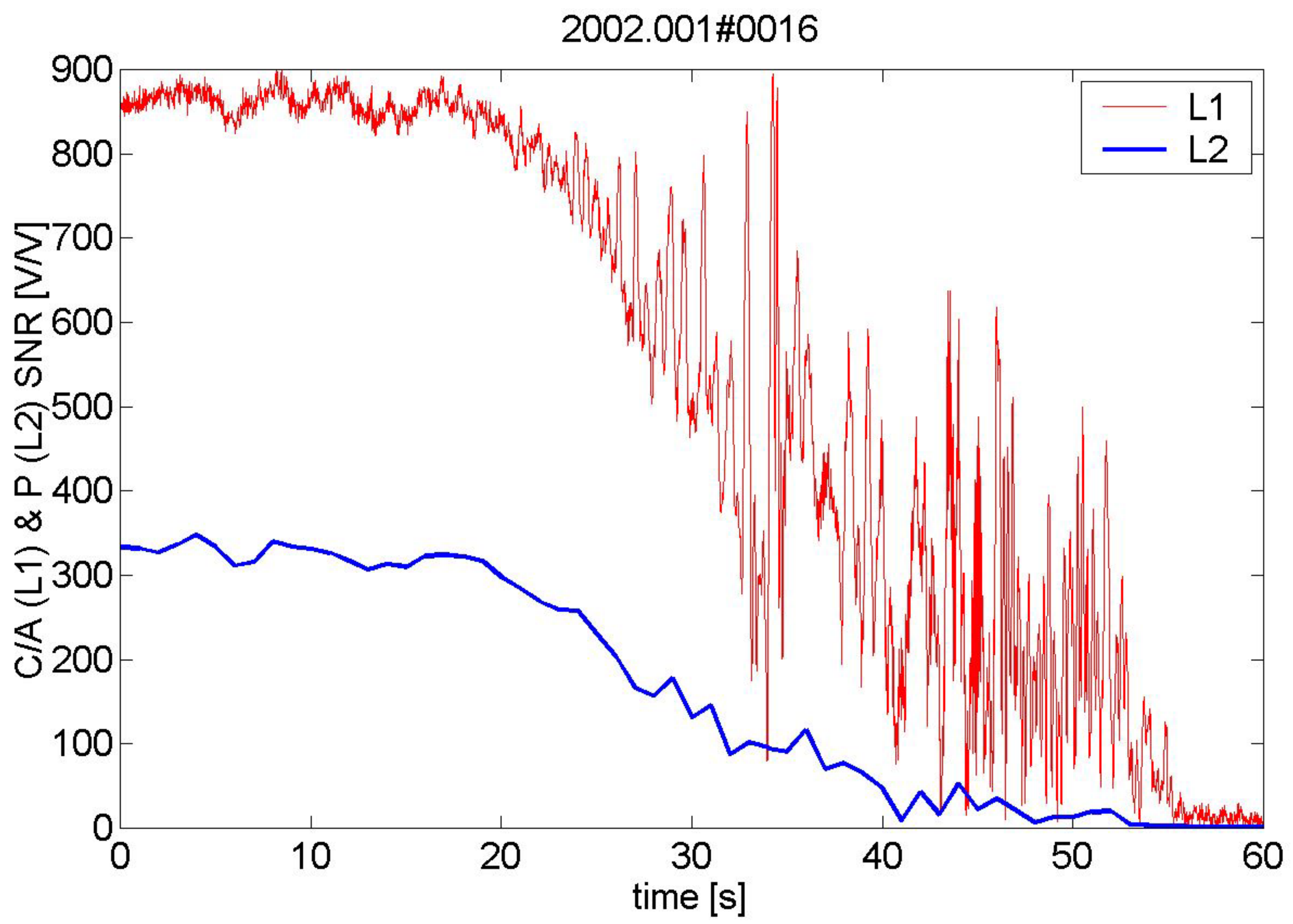


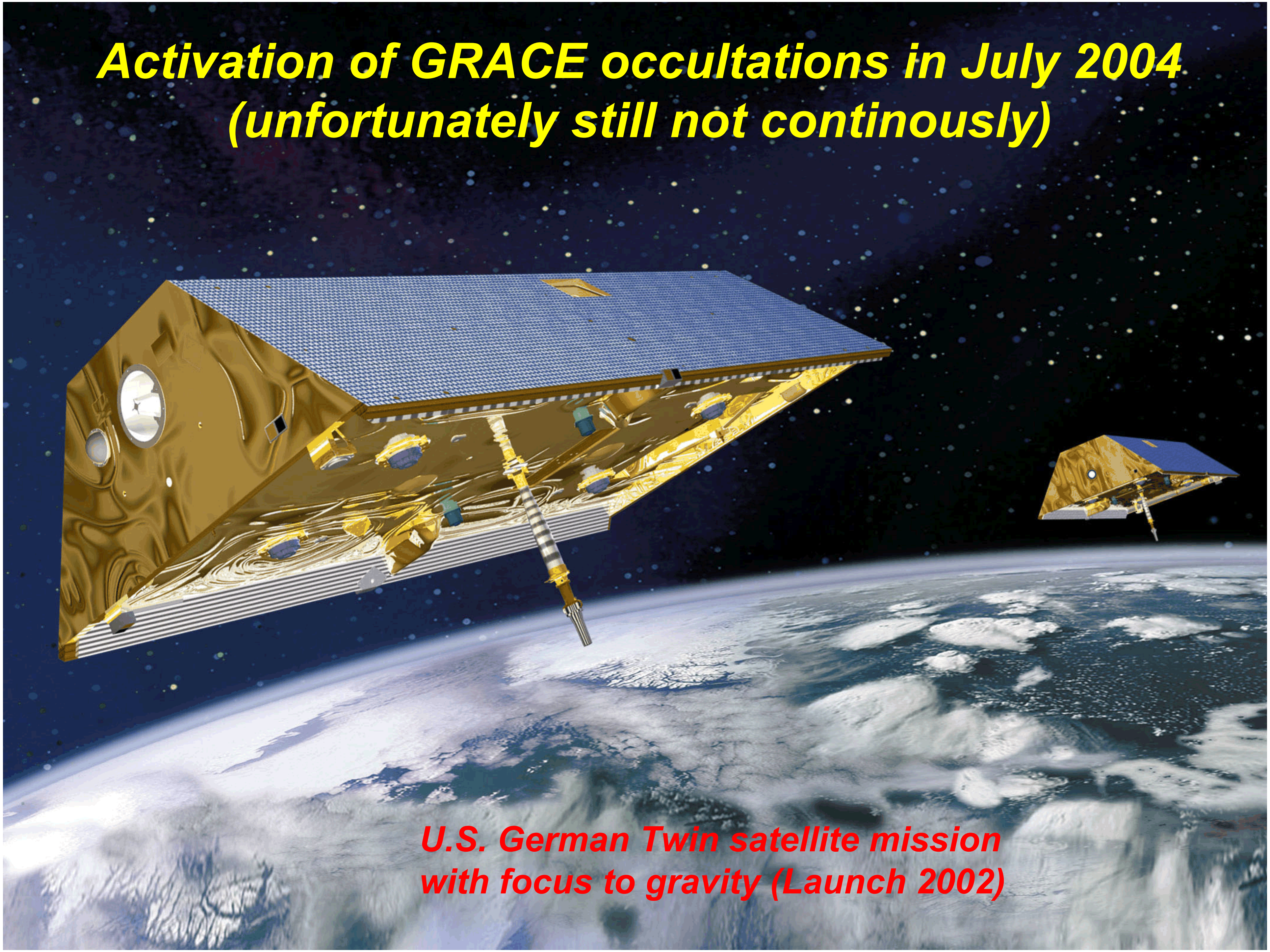
CHAMP: First measurements

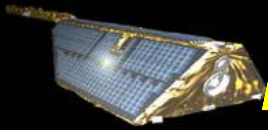


February 11, 2001

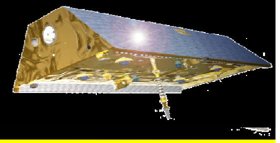
Signal to noise (A/S on)




Activation of GRACE occultations in July 2004
(unfortunately still not continously)
U.S. German Twin satellite mission
with focus to gravity (Launch 2002)



First GRACE occ… …s (120 events)



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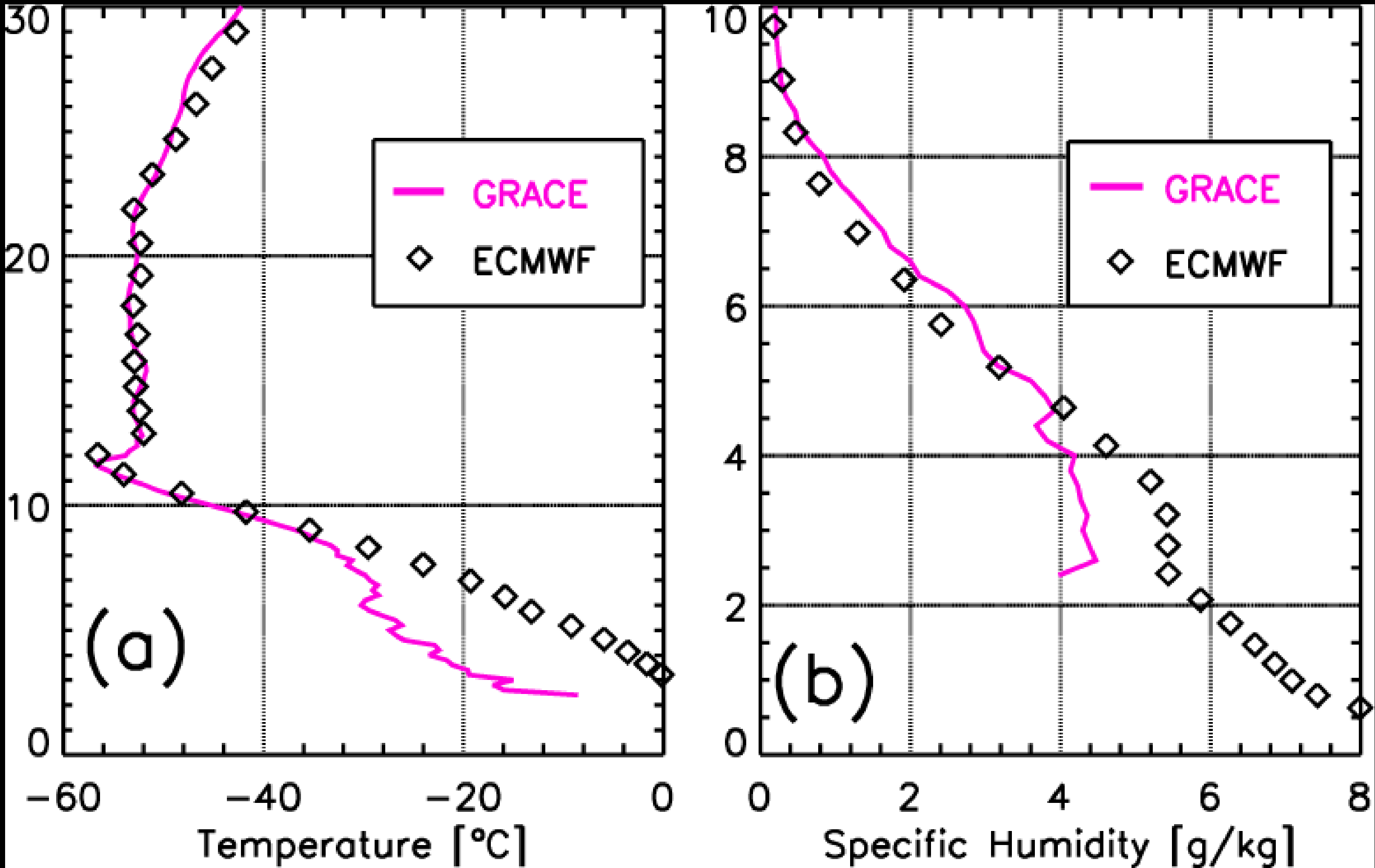
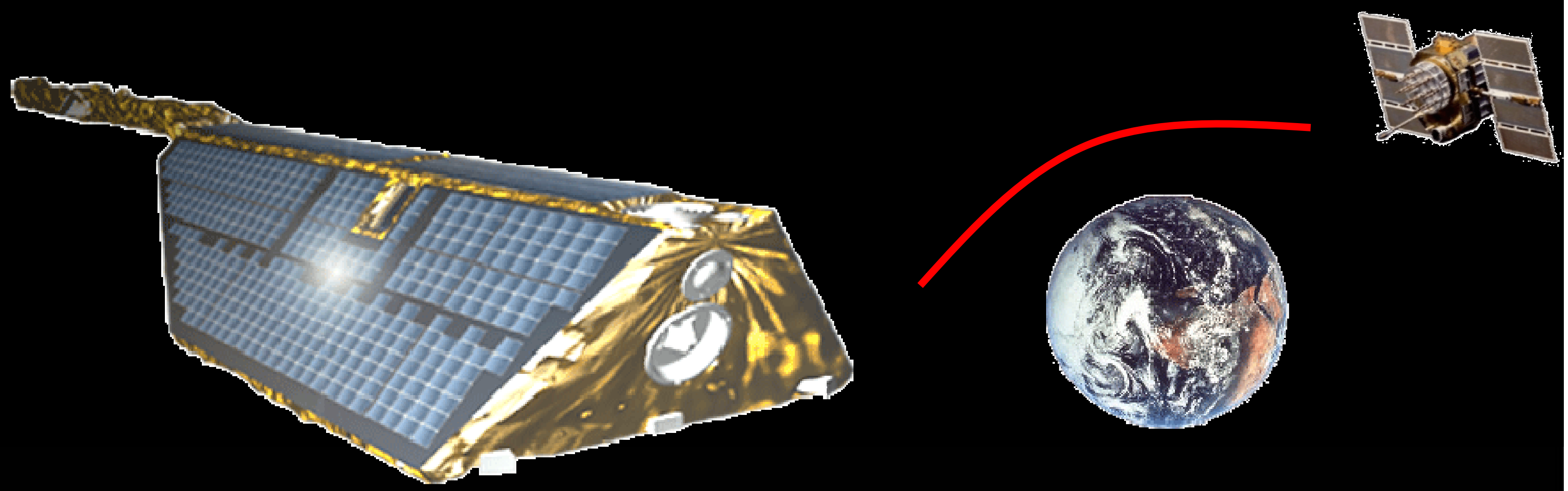
First profiles from GRACE

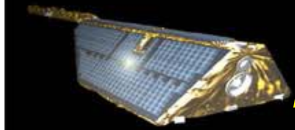


July 28, 2004; 06:10 UTC

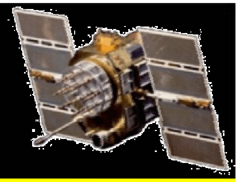
Wickert et al., 2005



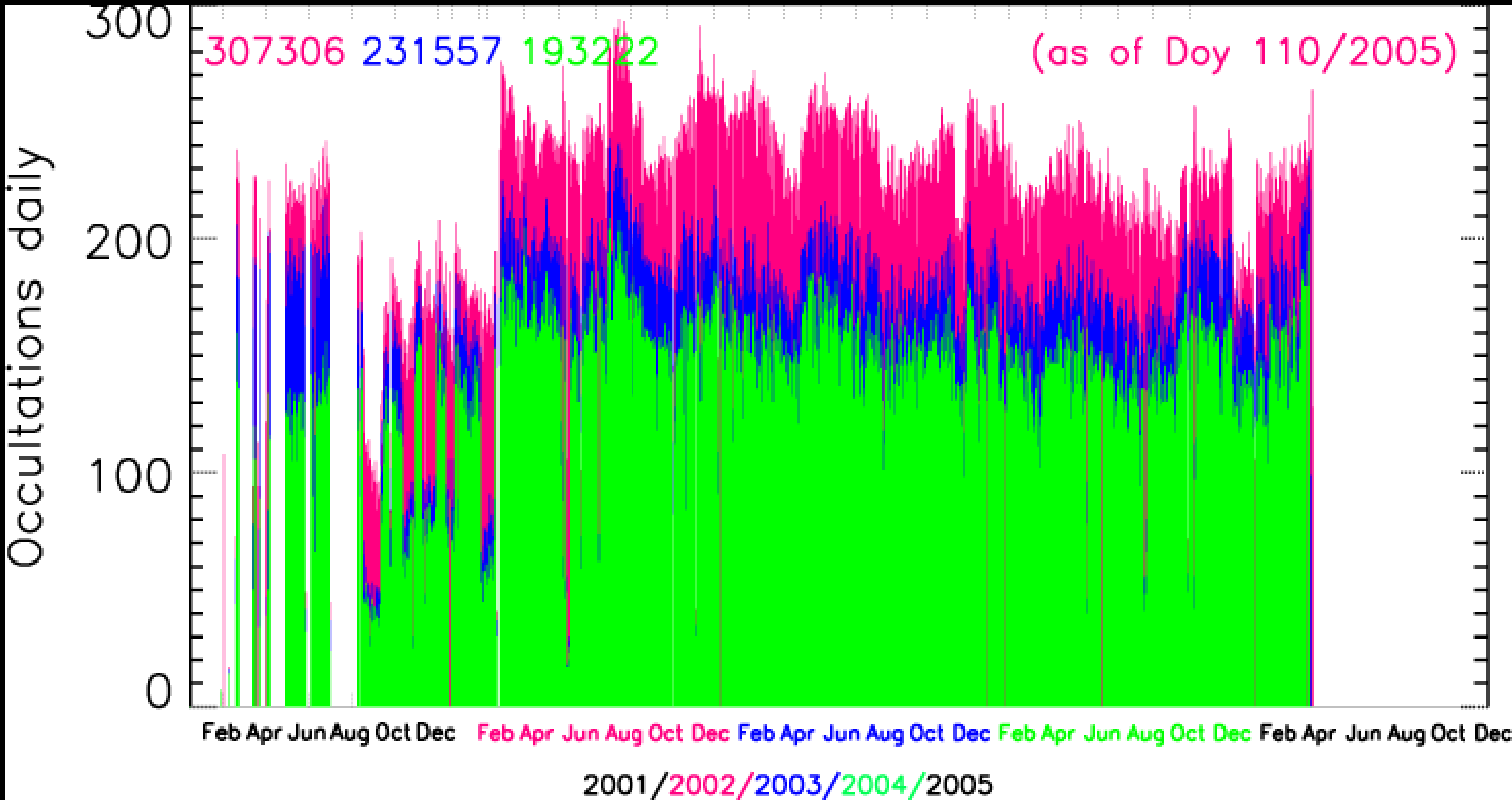
Data analysis



Neutral atmosphere: Occultations 2001-2005



1407 days; 307,306 occultations (~220 daily); Apr 20, 2005
231,557 phase delays (~75 %); 193,222 profiles (~63%)



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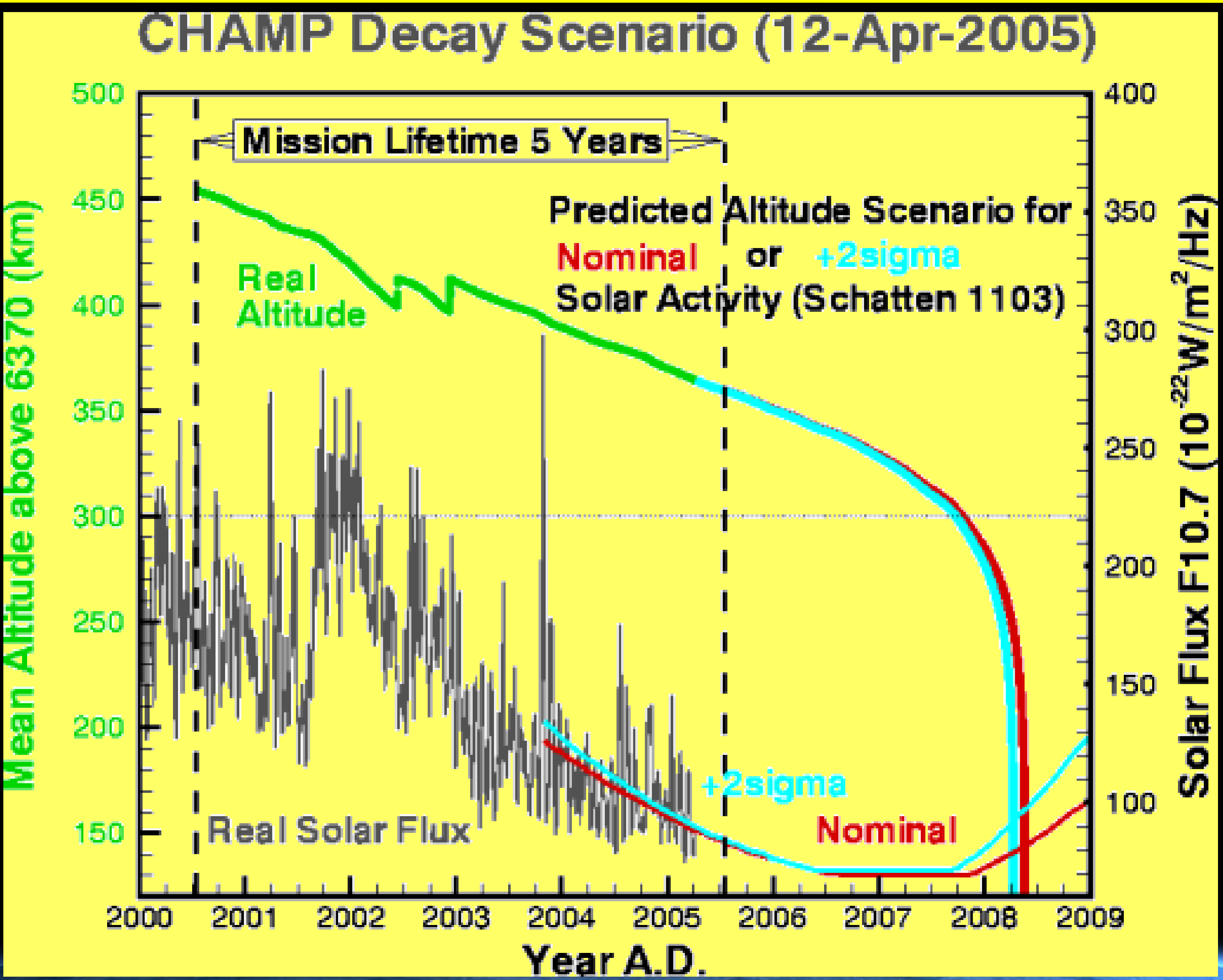
Expected mission duration: end 2007



J. Wickert, Science results from CHAMP, Taipeh, May 30, 2005

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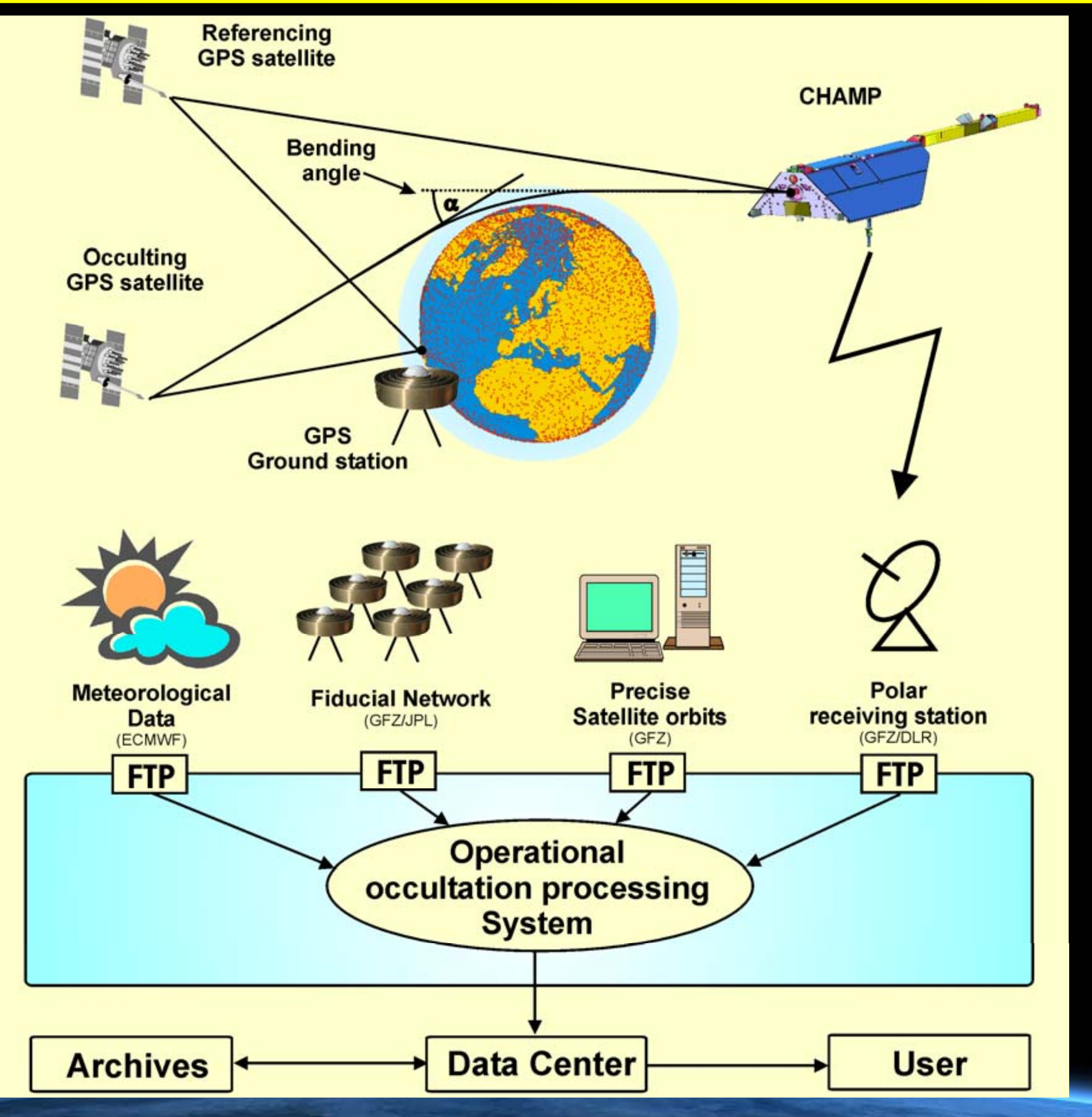
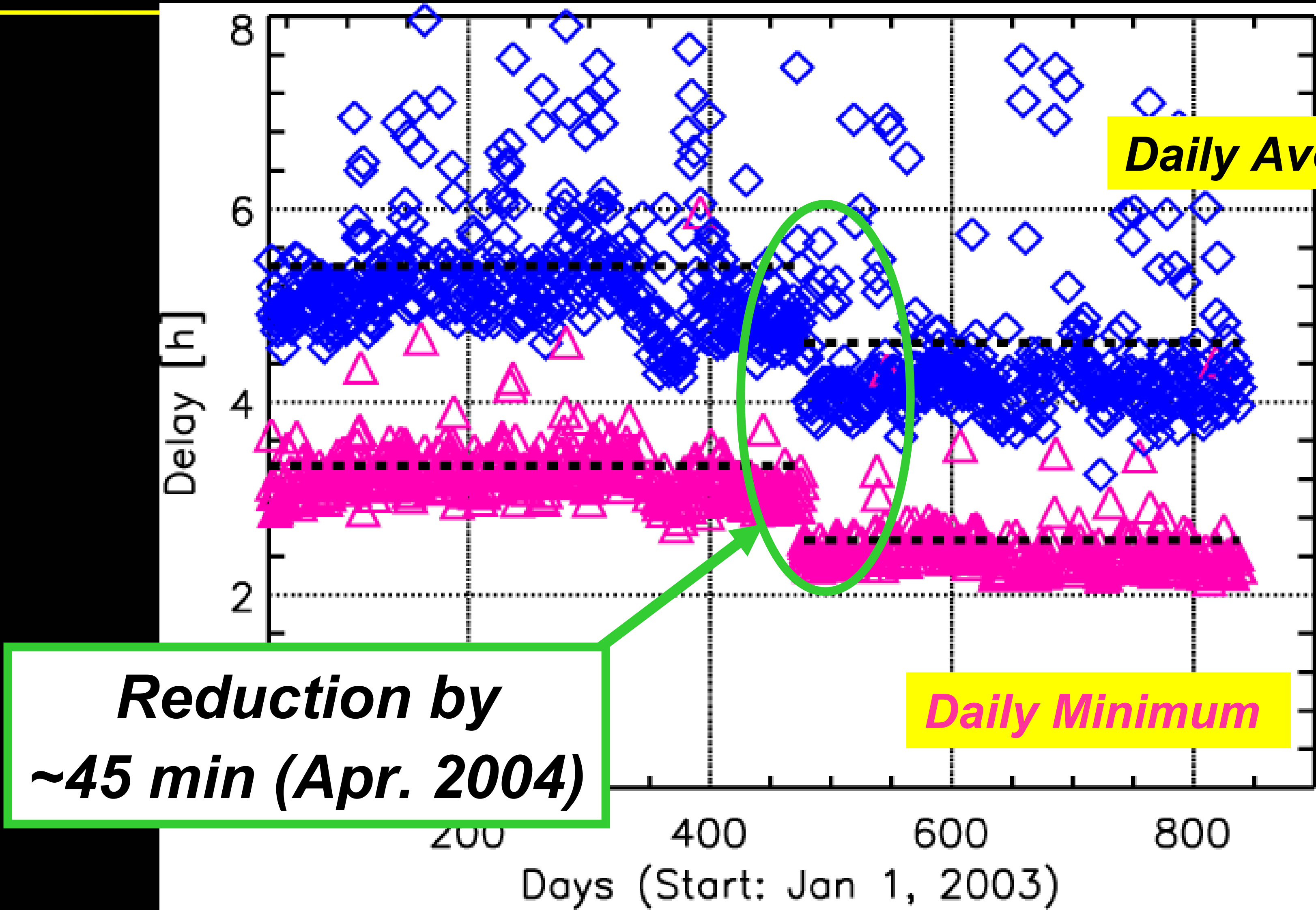
Operational RO infrastructure



Latency of path delays



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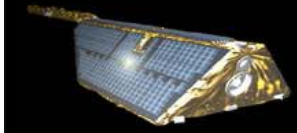

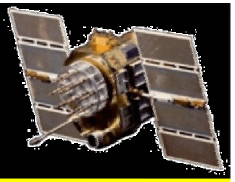

Calibration: satellite orbits

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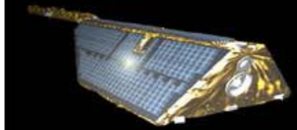
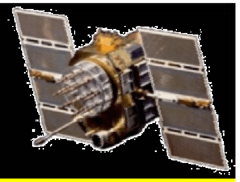
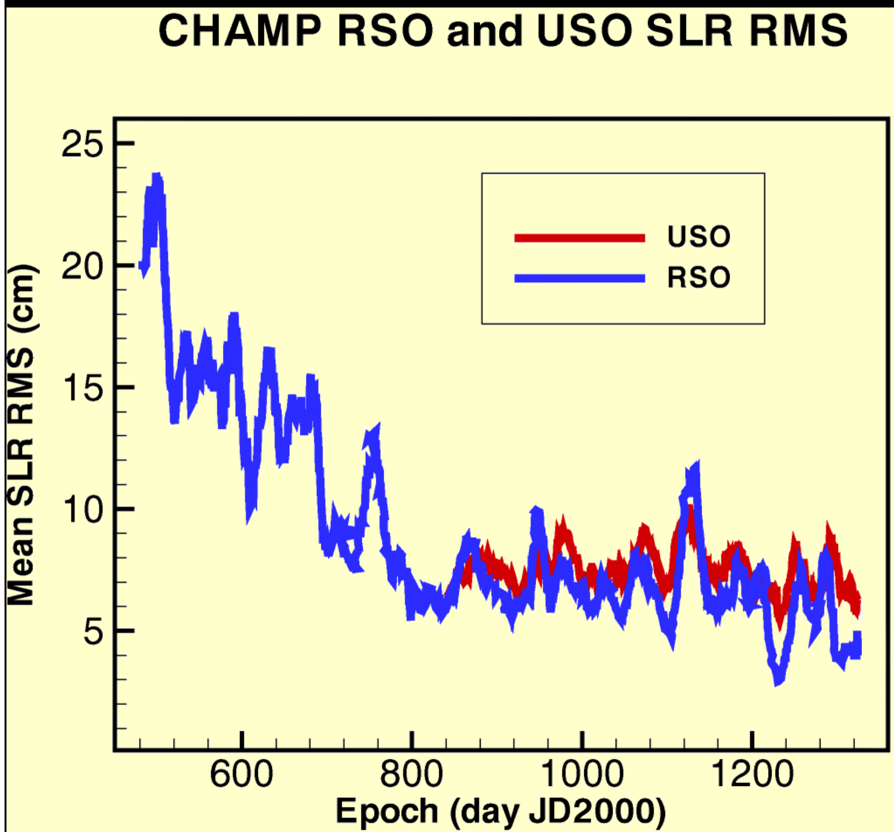
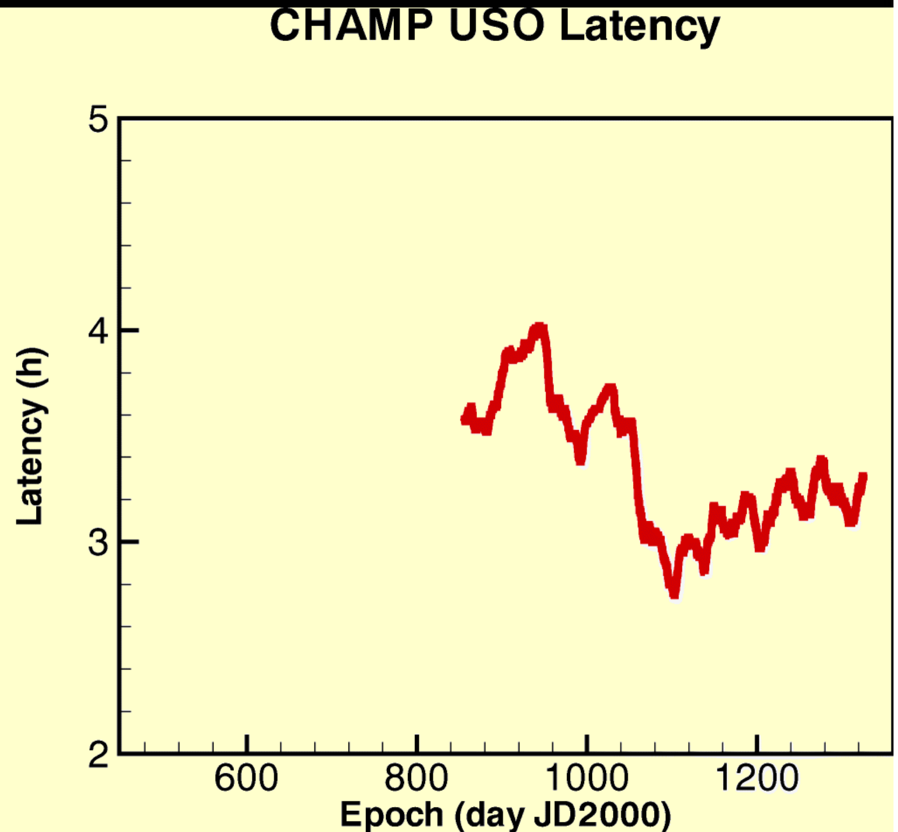


CHAMP orbit accuracies





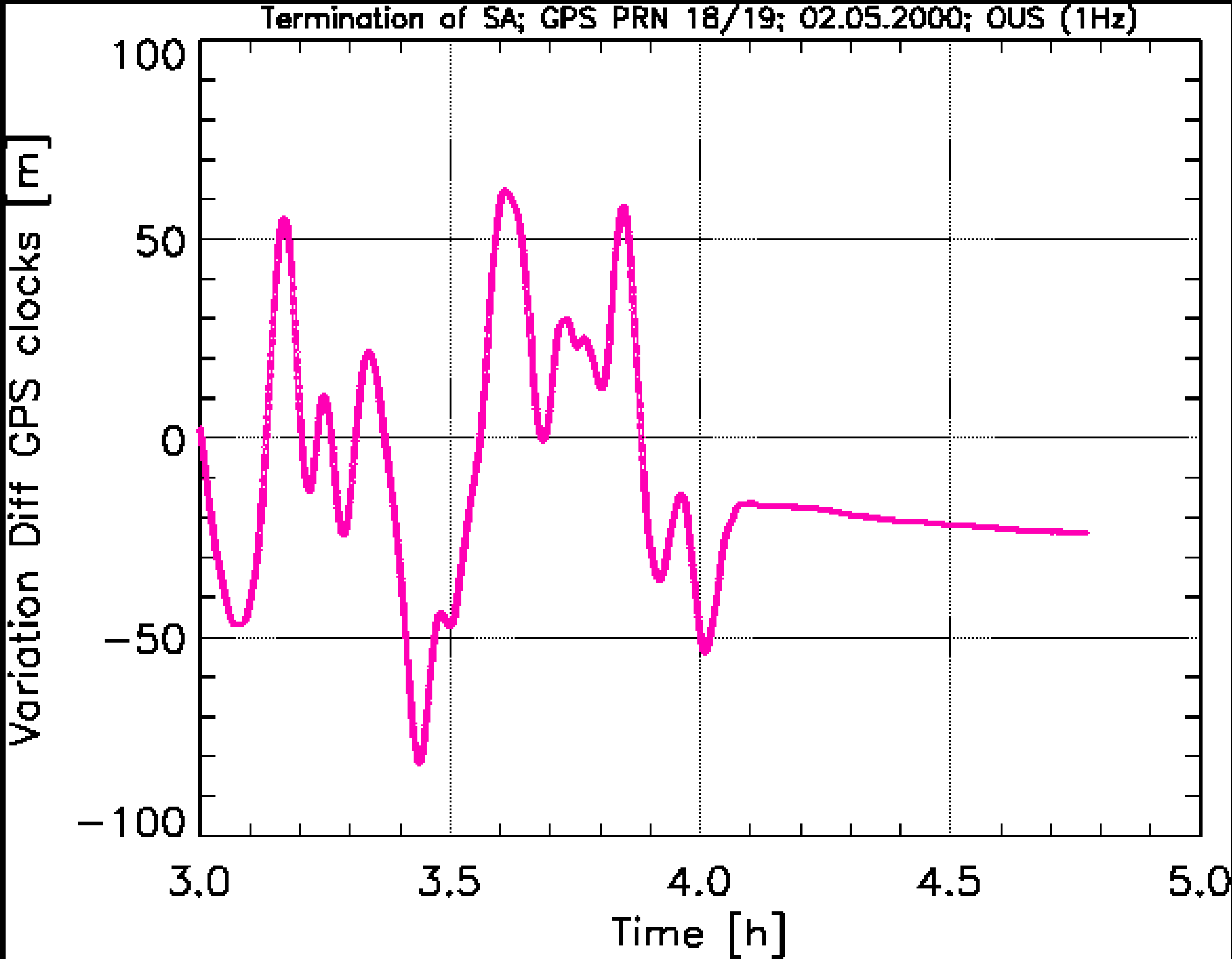


RSO: Rapid Science Orbit

USO: Ultra rapid Science Orbit

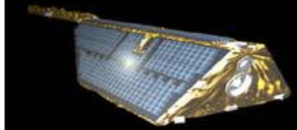
GPS processing: Differencing

Termination of SA on May 2, 2000

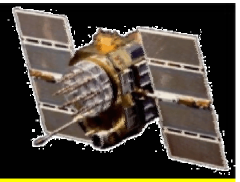


SA activated: rates of ~ 1 m/s

Wickert et al., 2001



Differencing



Double differencing (GPS/MET):

- „bad“ LEO oscillator
- GPS oscillators with activated S/A)

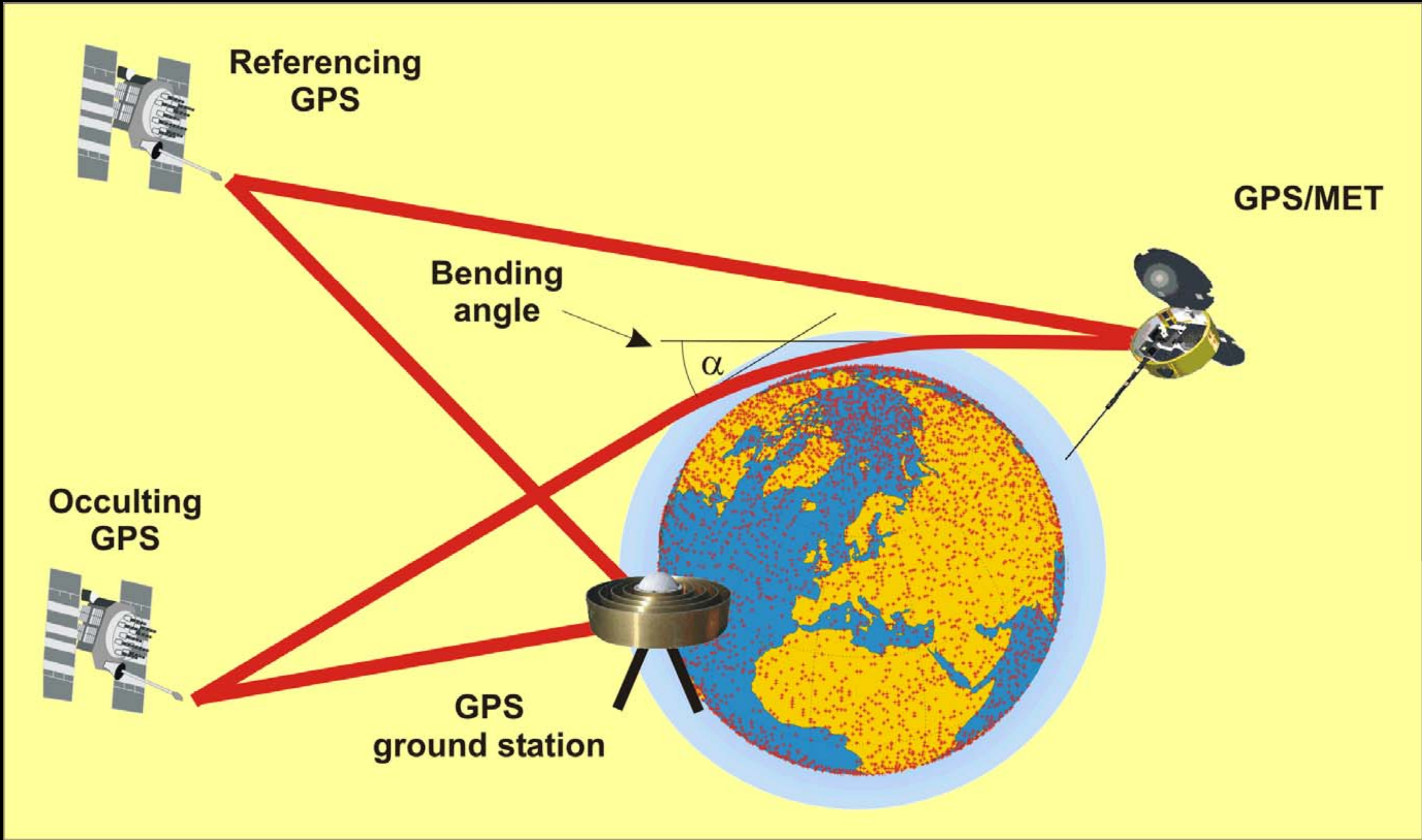
Single differencing (CHAMP):

- „bad“ LEO oscillators
- GPS with deactivated S/A

Zero differencing (GRACE):

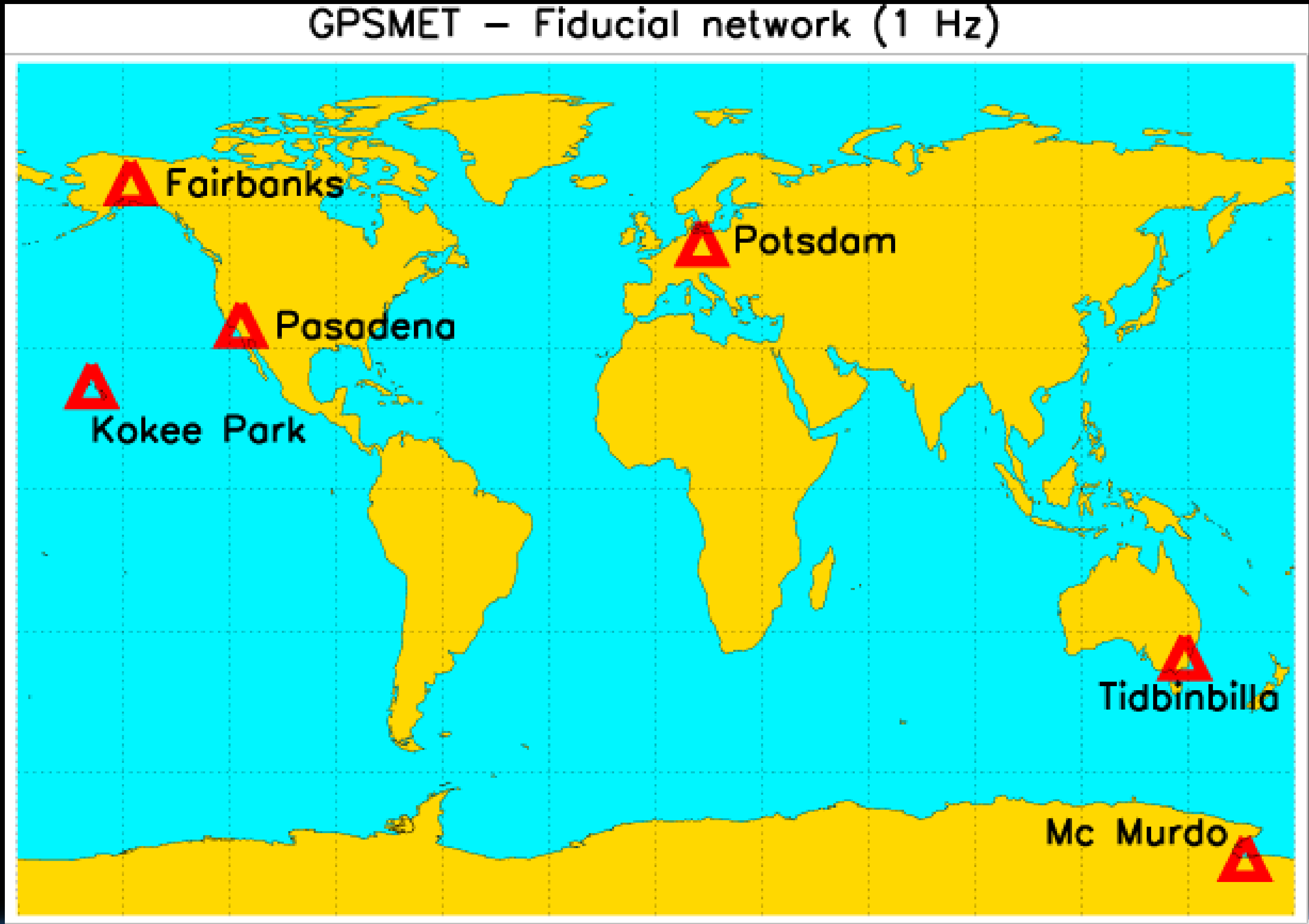
- stable LEO oscillator
- GPS with deactivated S/A

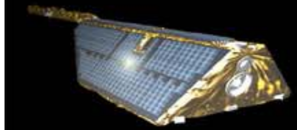
Double differencing



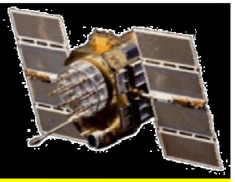
GFZ POTSDAM

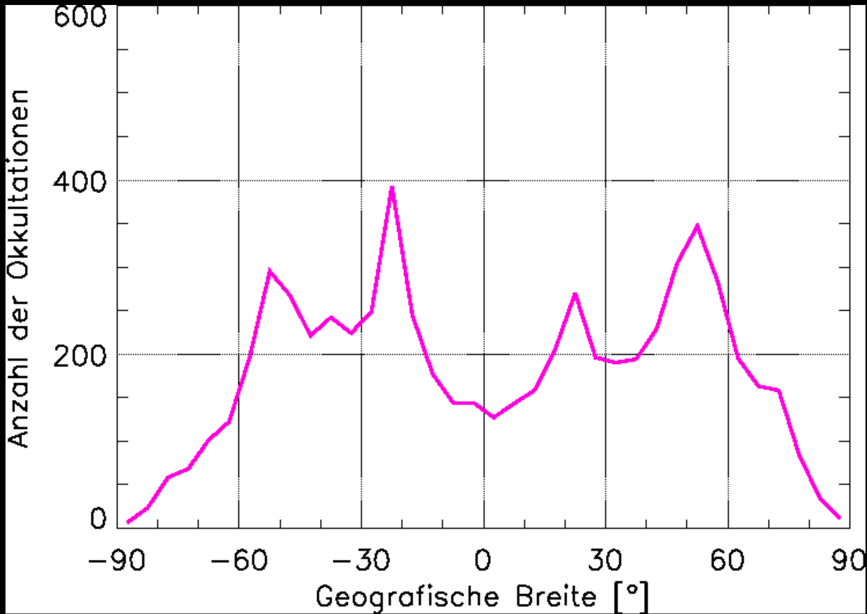
GPS/MET: H/R network

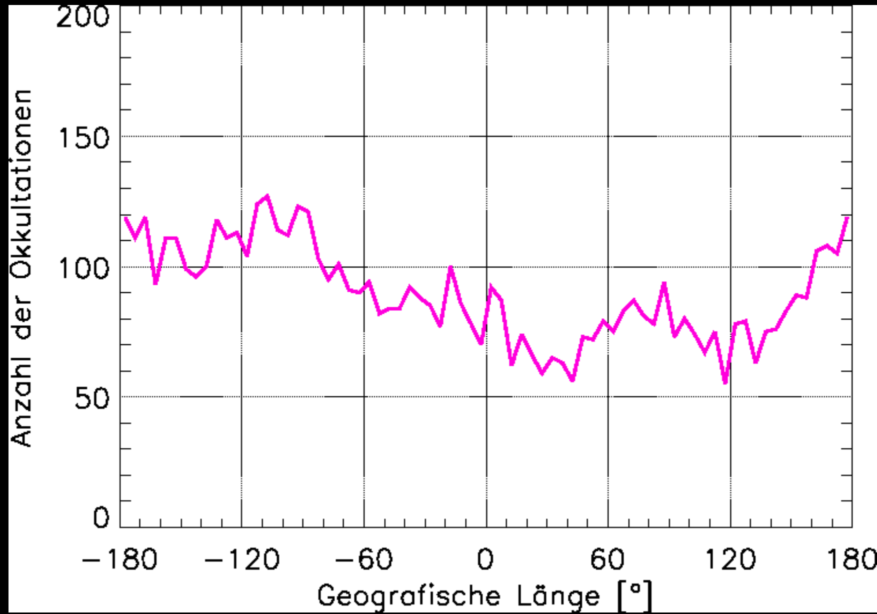




GPS/MET: Global distribution





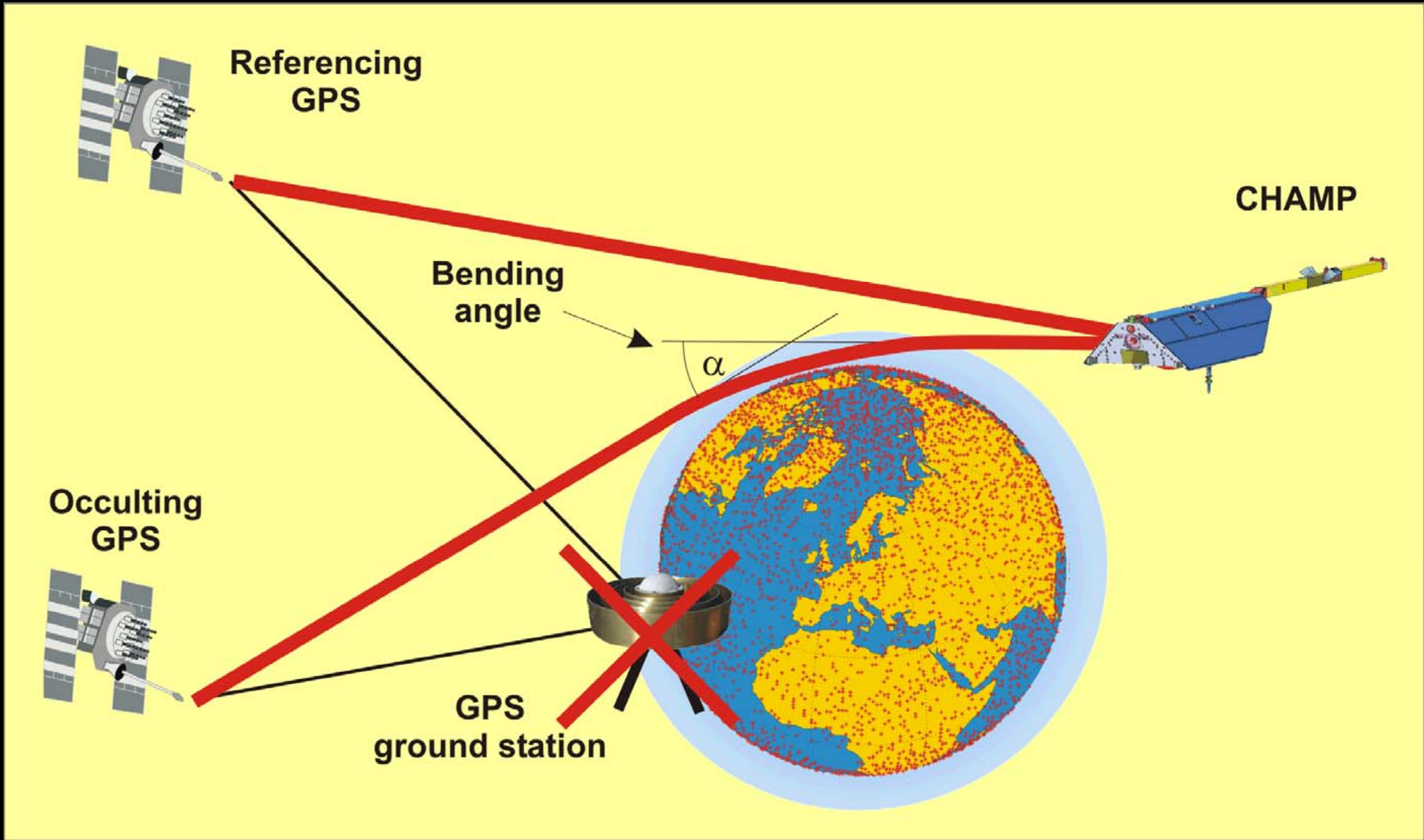


Wickert 2002

Geographical distribution GPS/MET occultations

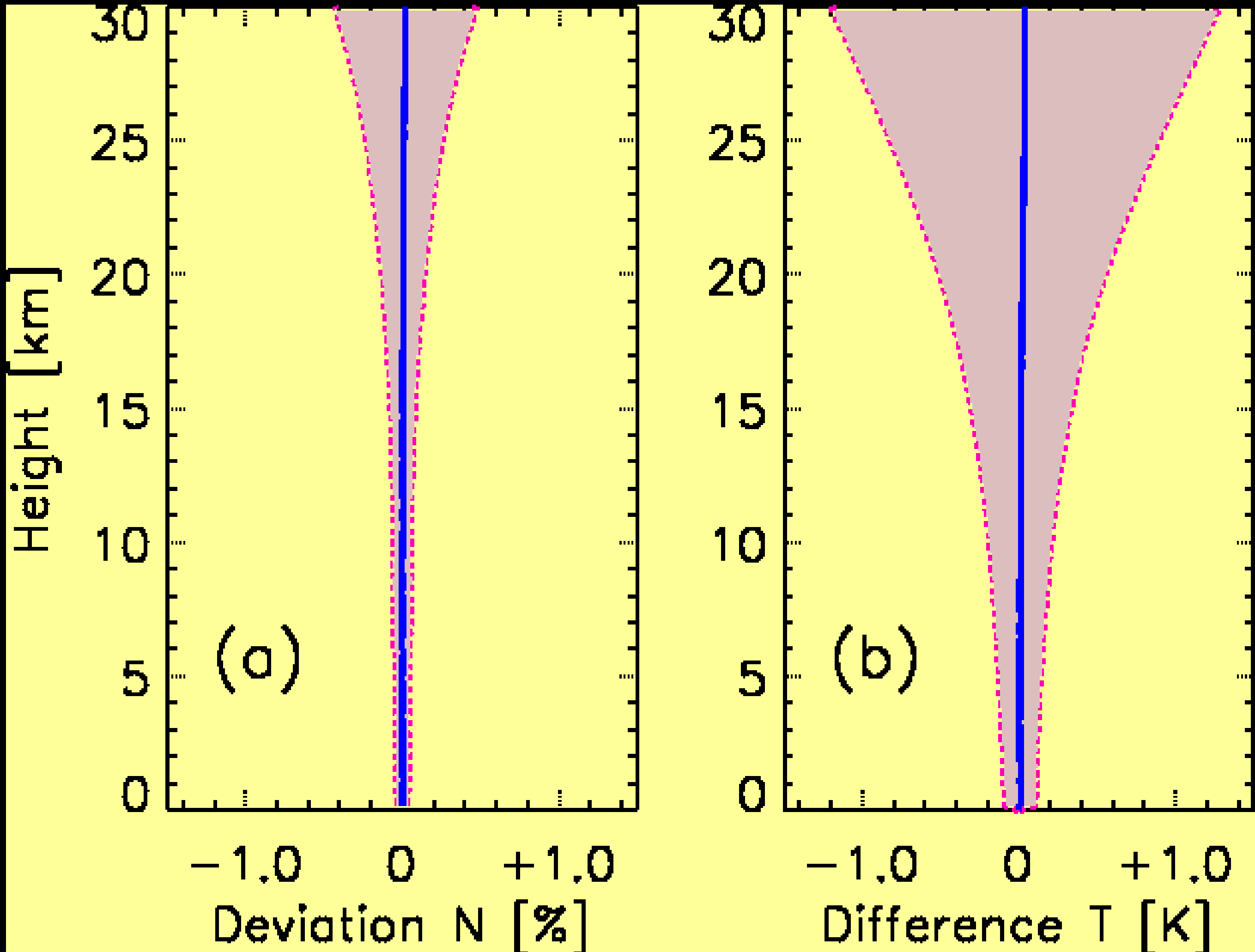
(6,464 occultations)

Single differencing

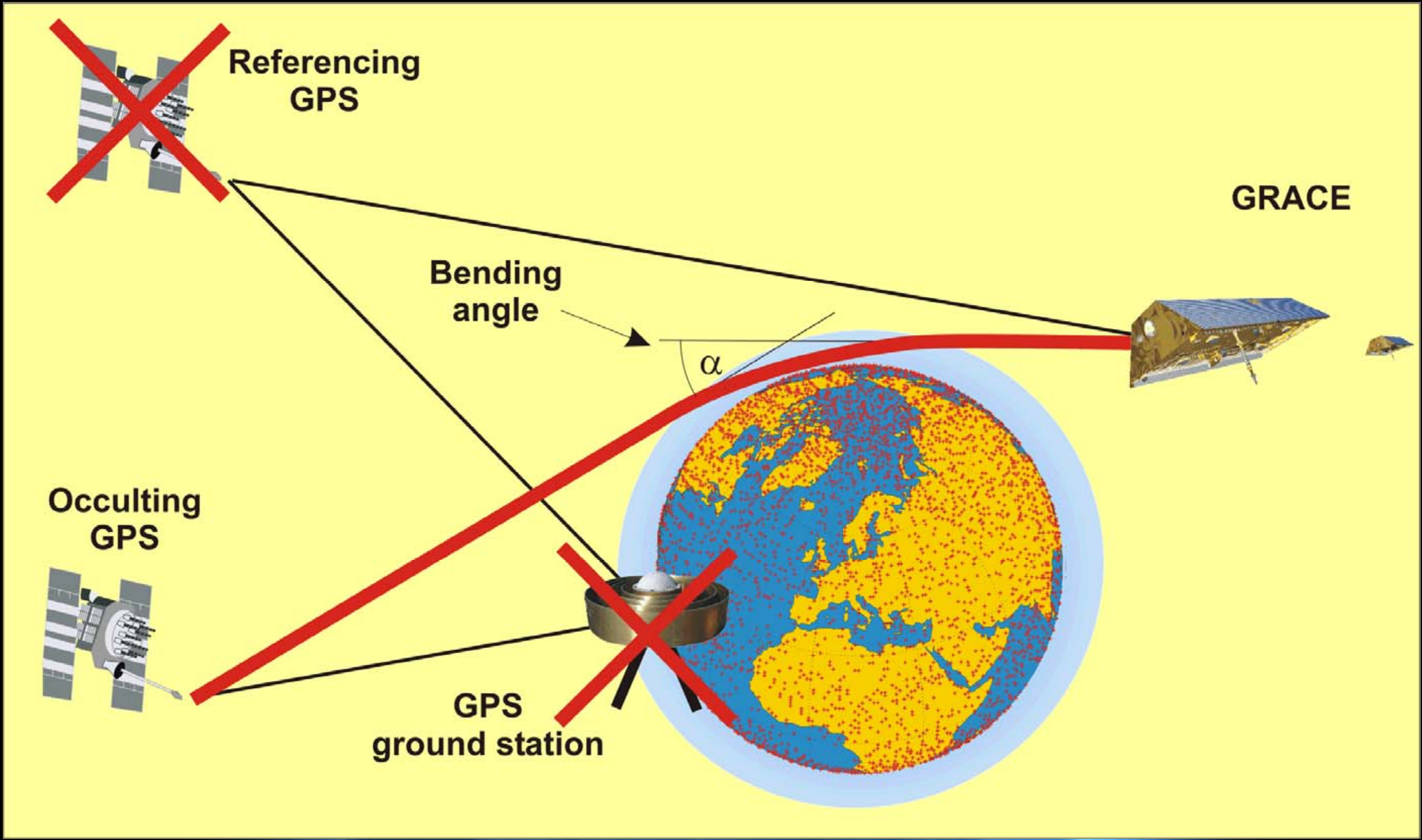


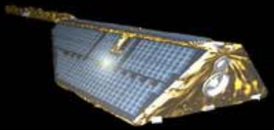
Space-based single differencing

Comparison of 2 Data sets (436 Profile April 19-21, 2001) DDIFF/SDIFF

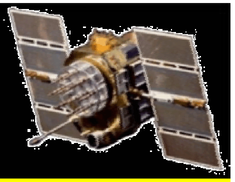


Zero differencing

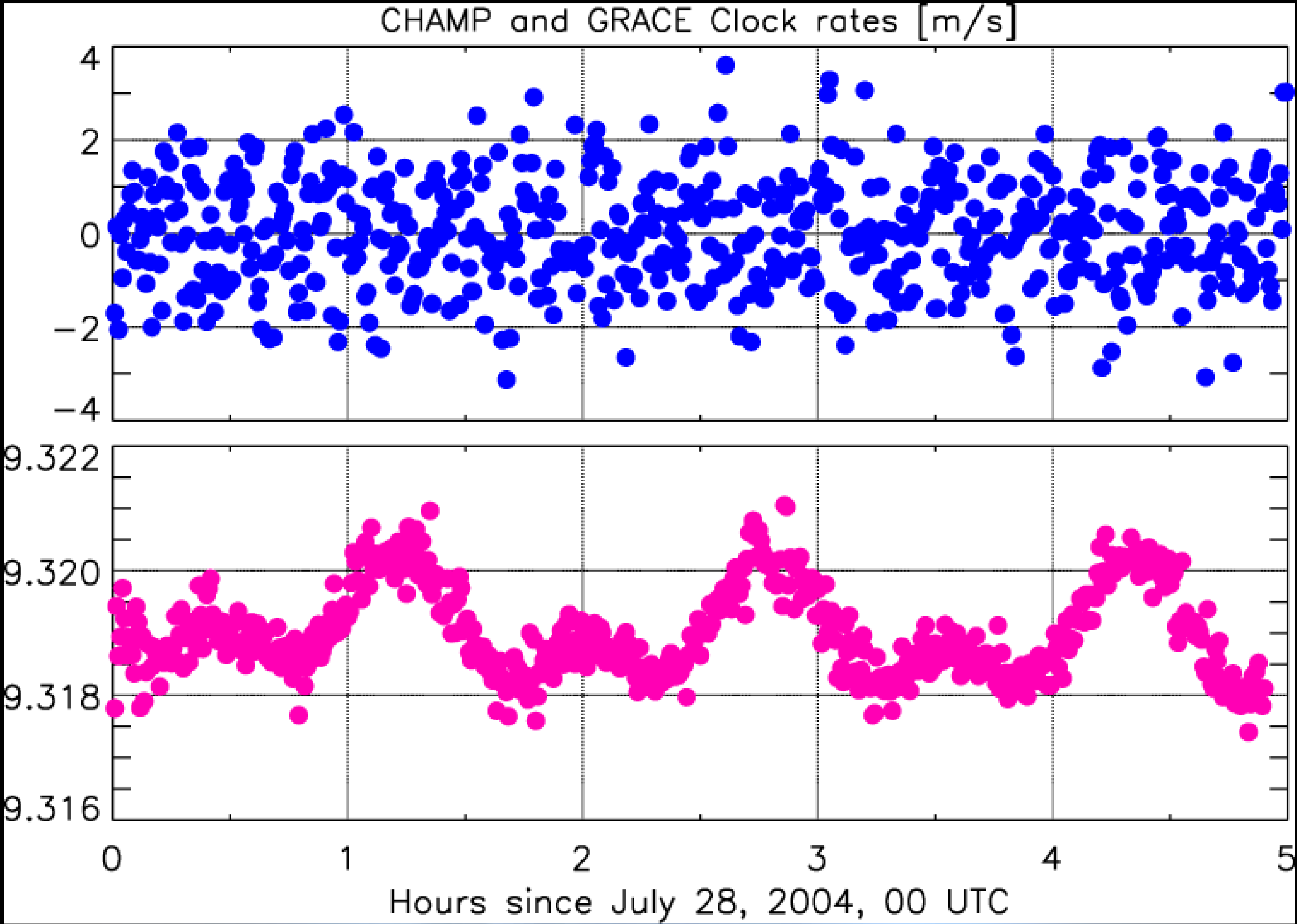




CHAMP and GRACE clocks



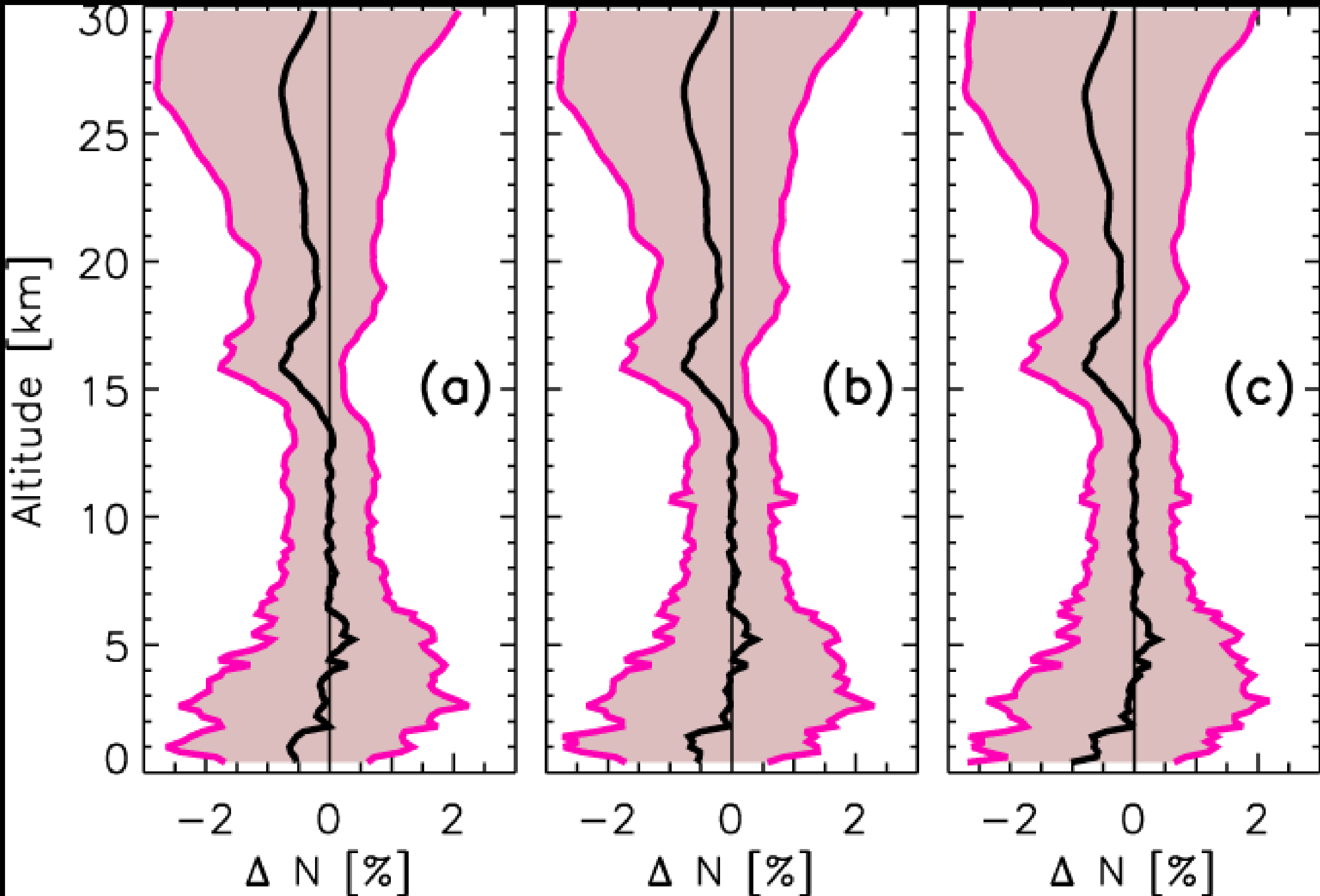
Significant more stable GRACE clock



Wickert et al., 2005

Zero Differencing: GRACE

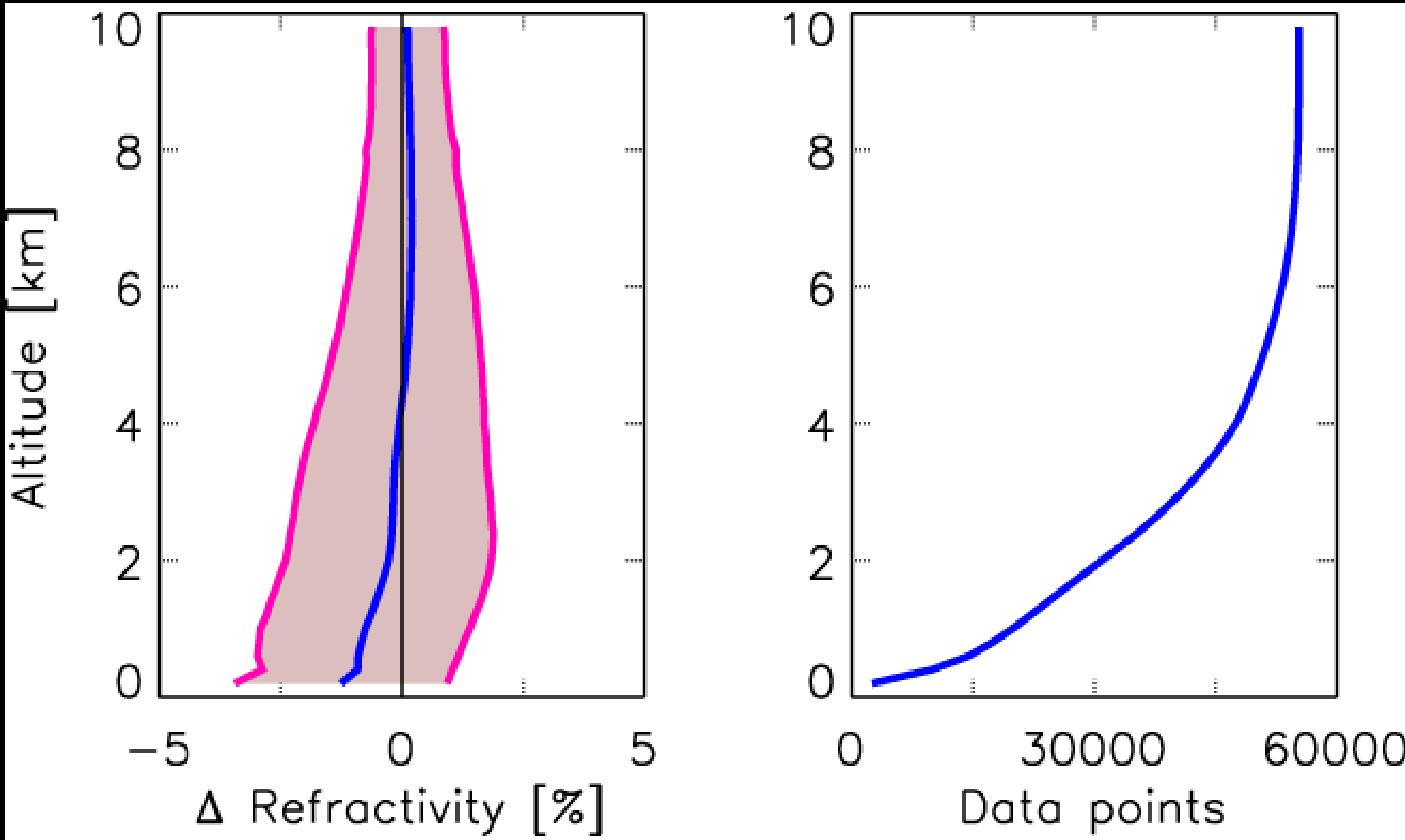
Deviations in relation to ECMWF (96 profiles)



Differencing a) double b) single c) zero

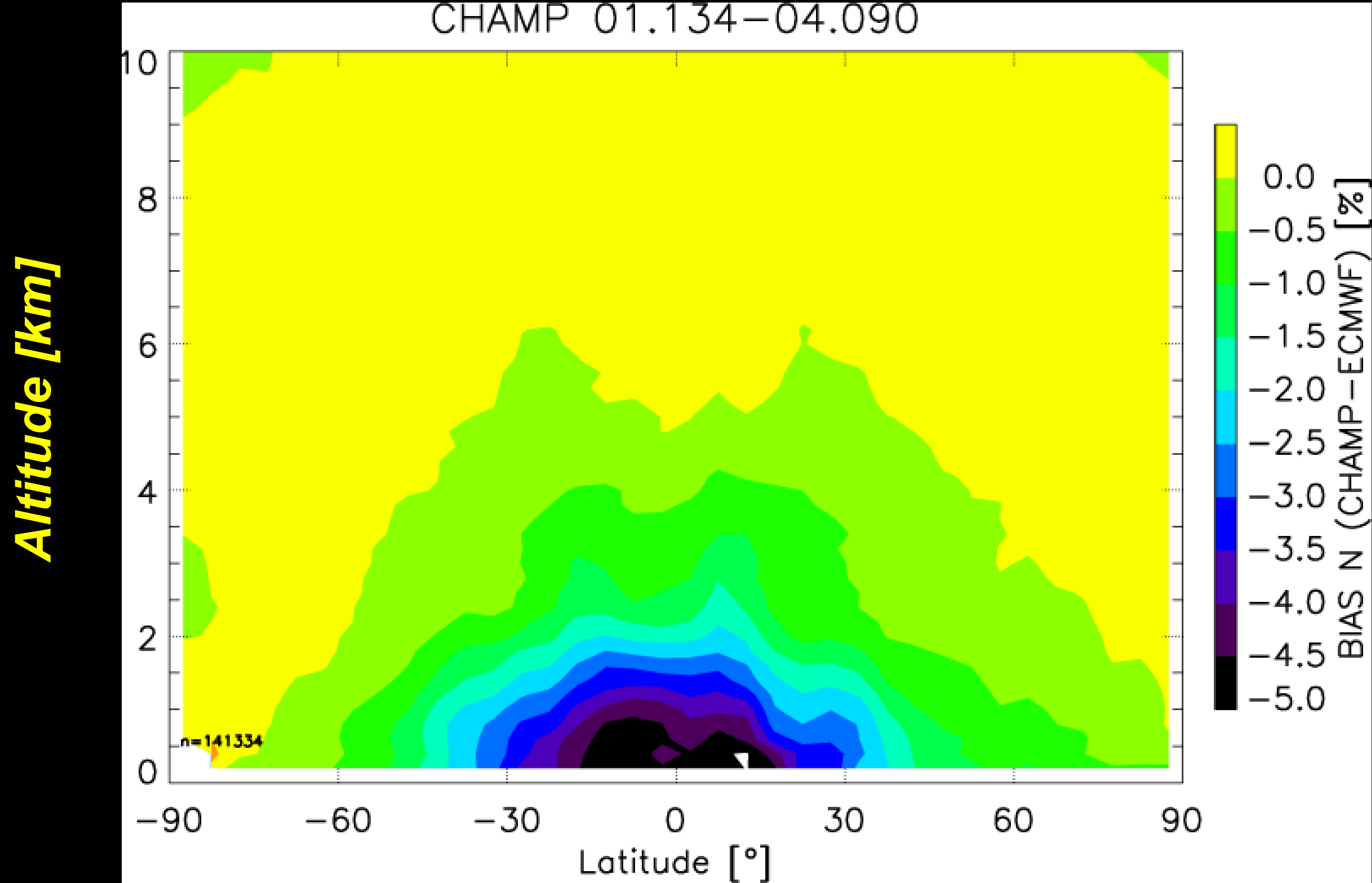
Lower troposphere bias

Comparsion with ECMWF

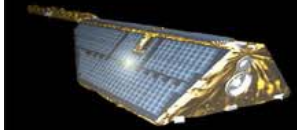


Comparsion with ECMWF (~145.000 profiles)

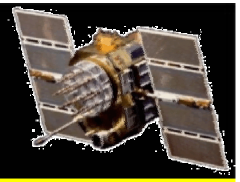
Bias refractivity



GFZ POTSDAM

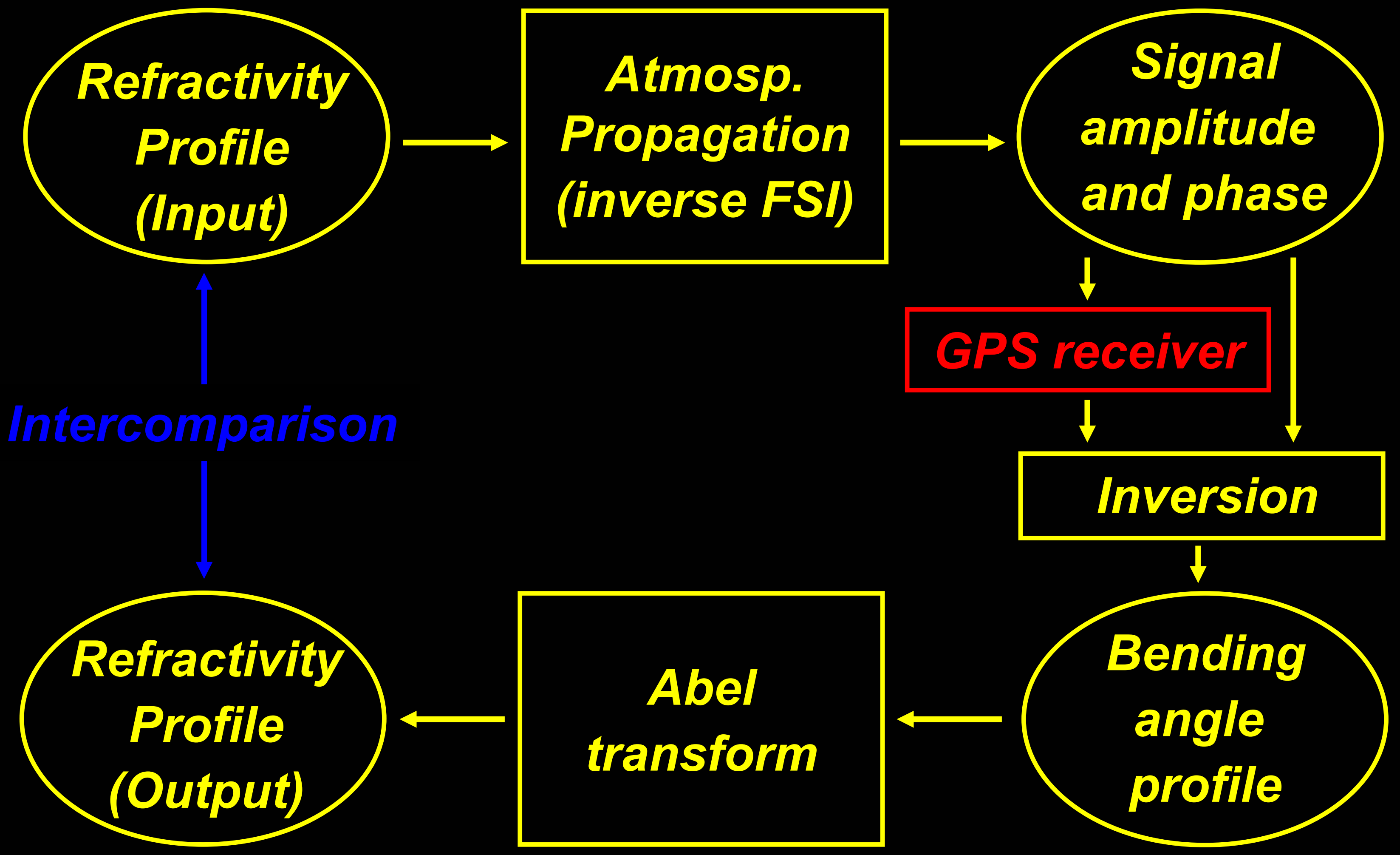


Negative refractivity bias

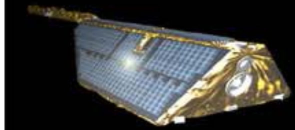


- *First reported by Rocken et al., 1997 (GPS/MET)*
- *Causes:*
  - *Signal loss due to critical refraction ($dN/dz < -157\ km^{-1}$) may induce neg. bias (e.g. Sokolovskiy)*
  - *Horizontal gradients (e.g. Healy, Sokolovskiy)*
  - *Signal tracking errors by the GPS receiver (Ao, Gorbunov, Beyerle)*
  - *Multipath (solved by FSI (Jensen)), operational application possible*
- *Lot of progress reached during the last years, also based on the CHAMP data*
- *Progress in signal acquisition and quality expected (e.g. COSMIC and MetOp)*

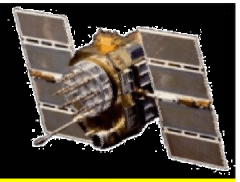
Simulations

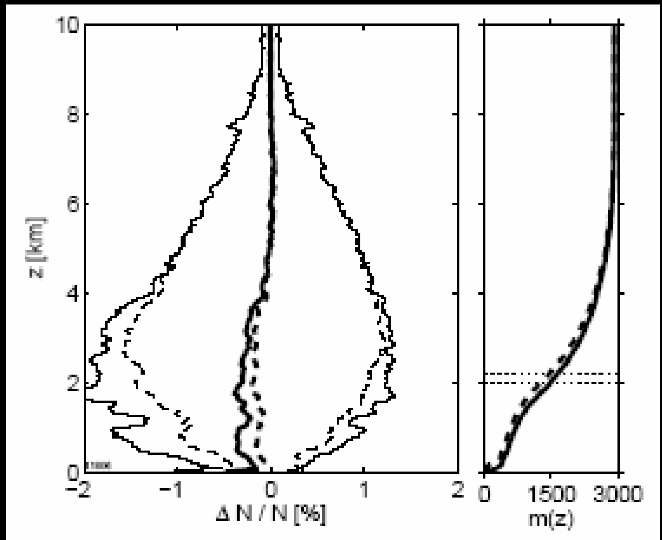


Beyerle et al., 2005 (the GPS receiver parameters should not be an accurate representation of the CHAMP receiver)



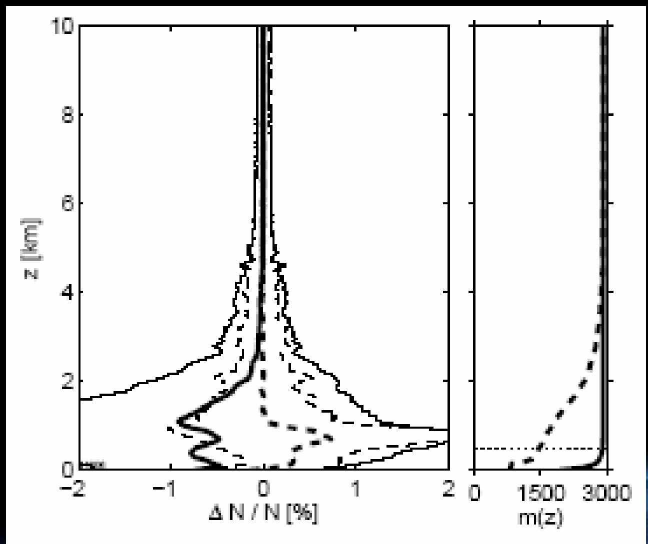
Study (3000 RS profiles)





2-quadrant, fly –wheeling (CHAMP like)

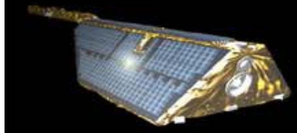
Unable to penetrate layers of critical refraction, above 3 km receiver induced errors (there is no critical refraction)

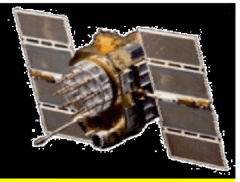


4-quadrant, Open Loop (OL)

Significant reduced bias, high yield in the LT, best performance, but also closed loop with bandwidth reduction provides good results

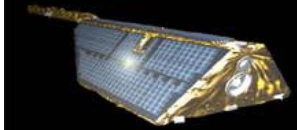
GFZ POTSDAM



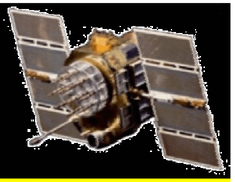


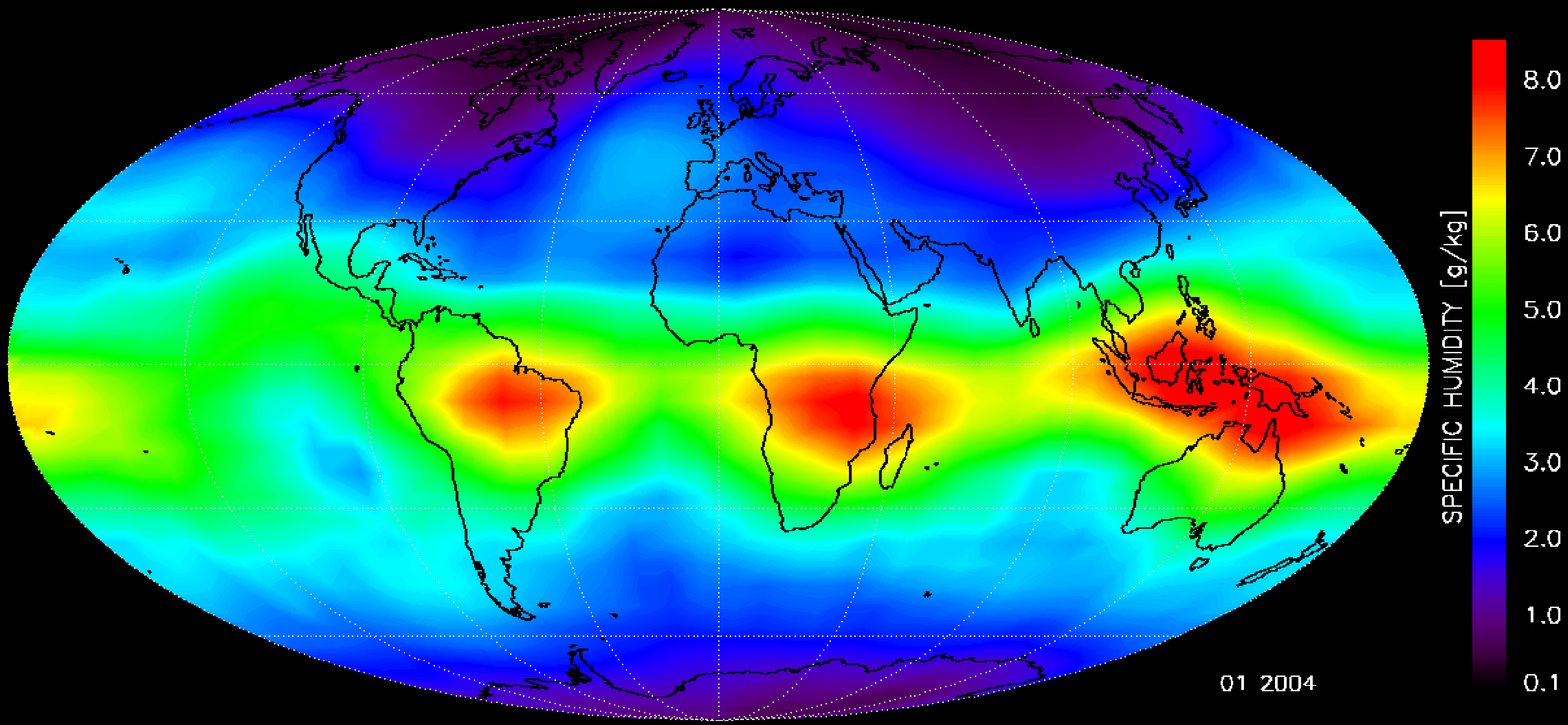
Global distribution water vapor

(quality will profit from improvements in LT retrieval/signal aquisition)



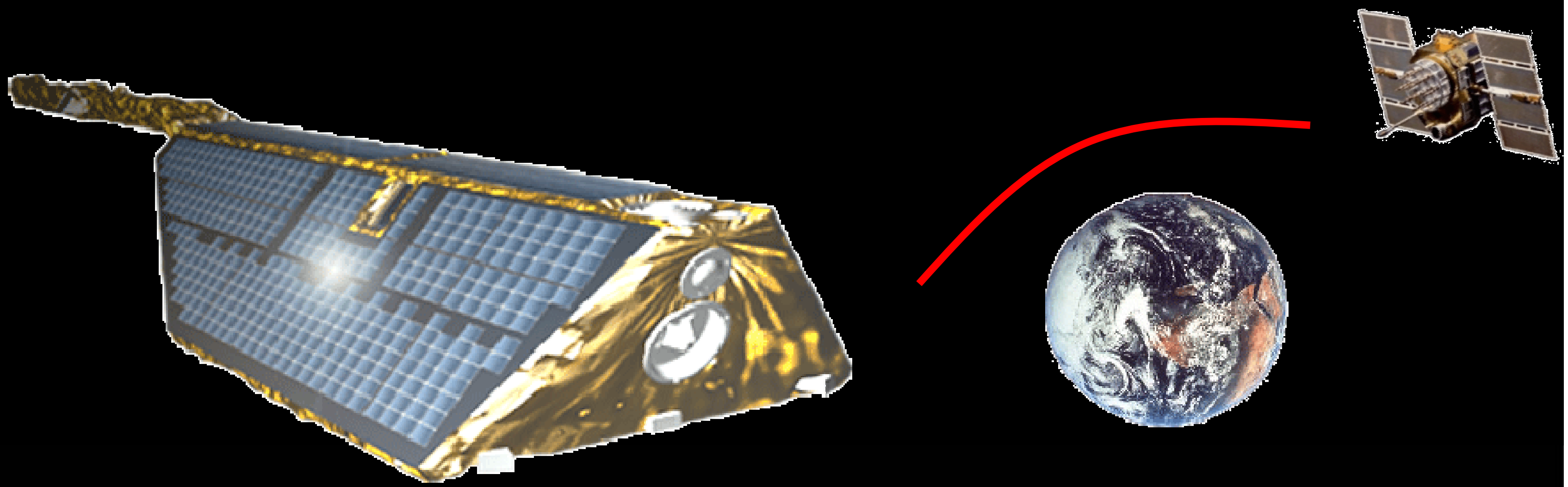
Water vapor





Monthly mean global water vapor distribution at 600 hPa (2004)

GFZ POTSDAM



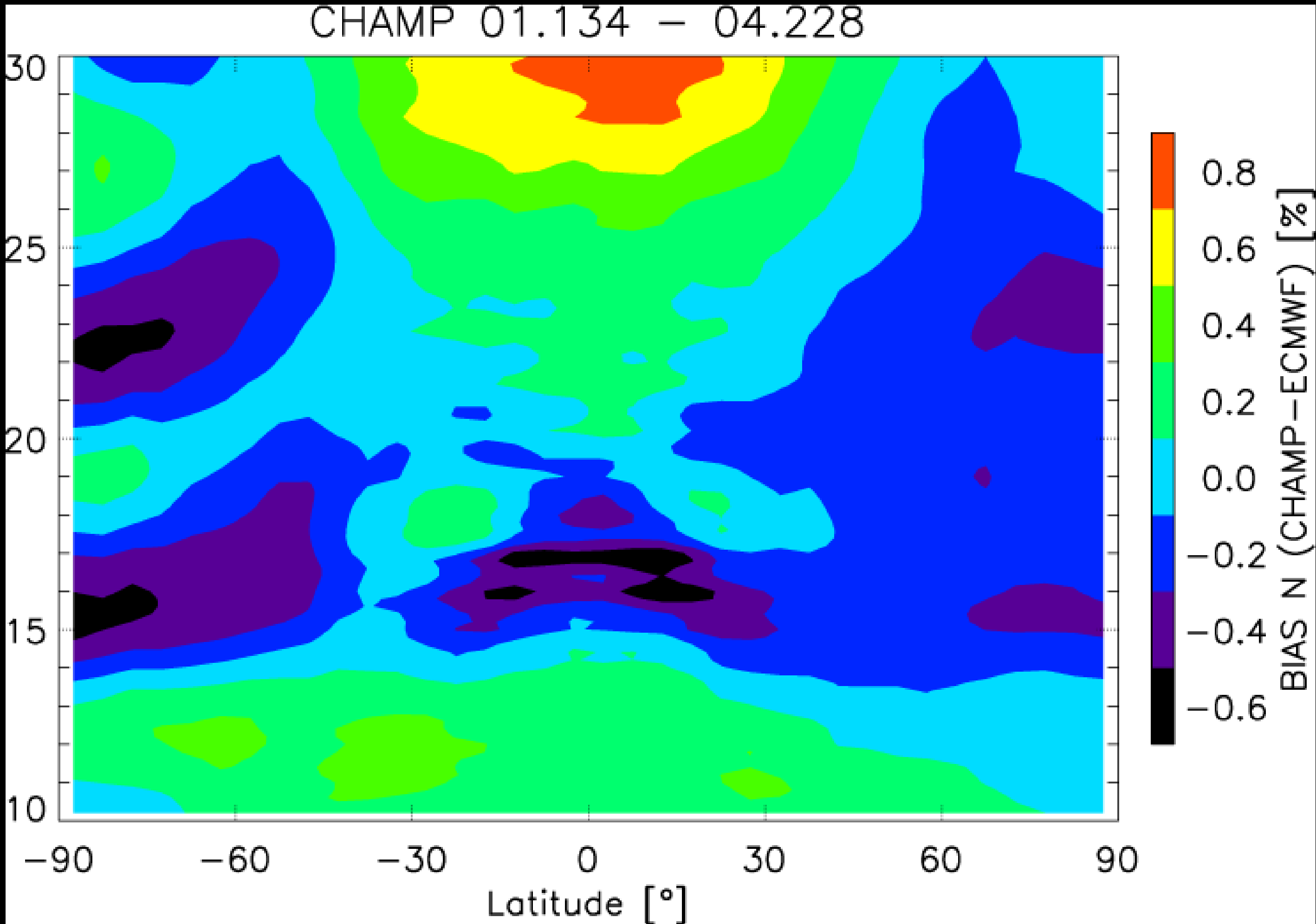
Validation

Meteorological Analyses (ECMWF)

CHAMP vs. ECMWF (~160.000 profiles)

Bias refractivity

Altitude [km]



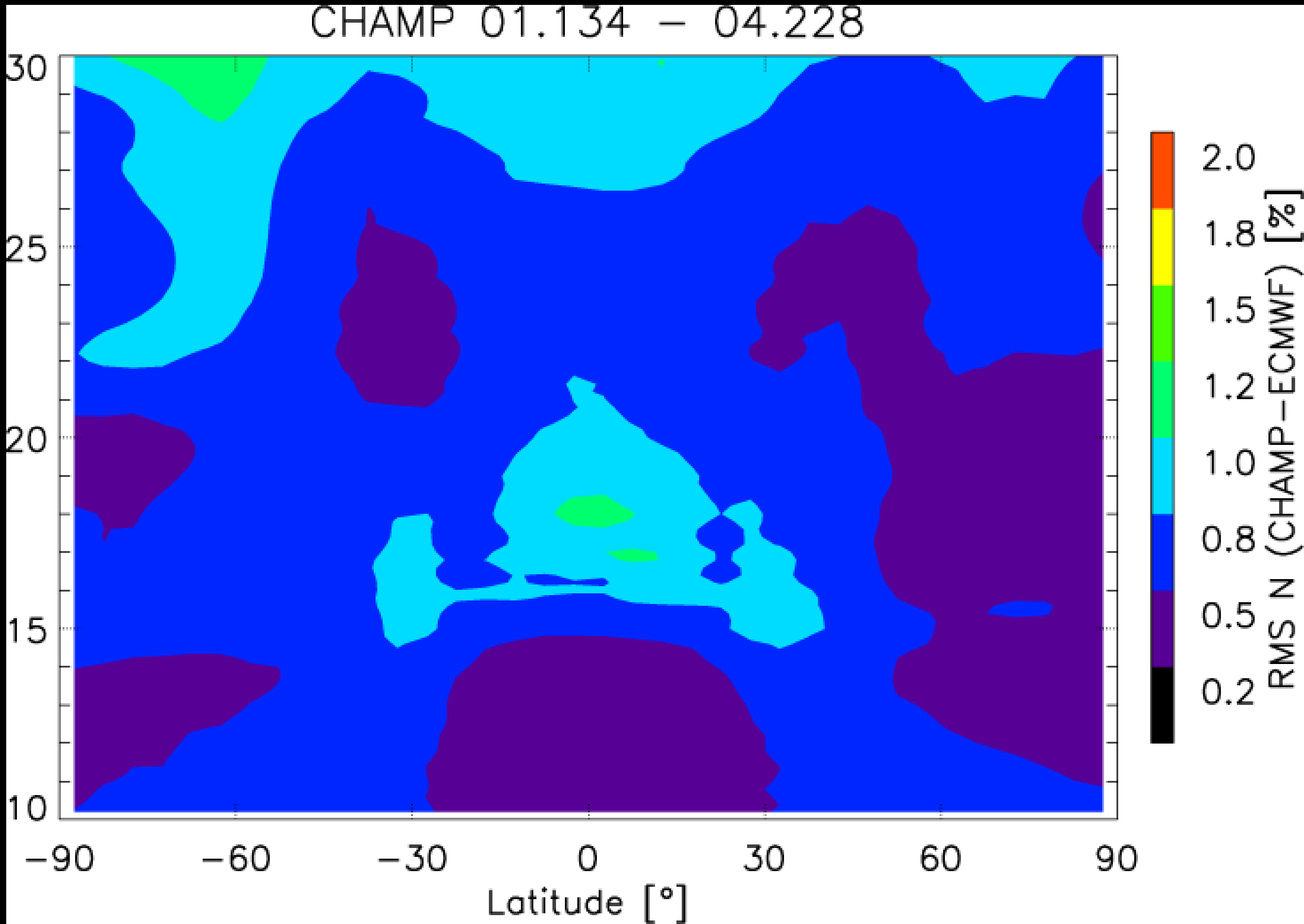
North-South asymmetry!

Wickert et al., 2005

CHAMP vs. ECMWF (~160.000 profiles)

Std Refractivity

Altitude [km]



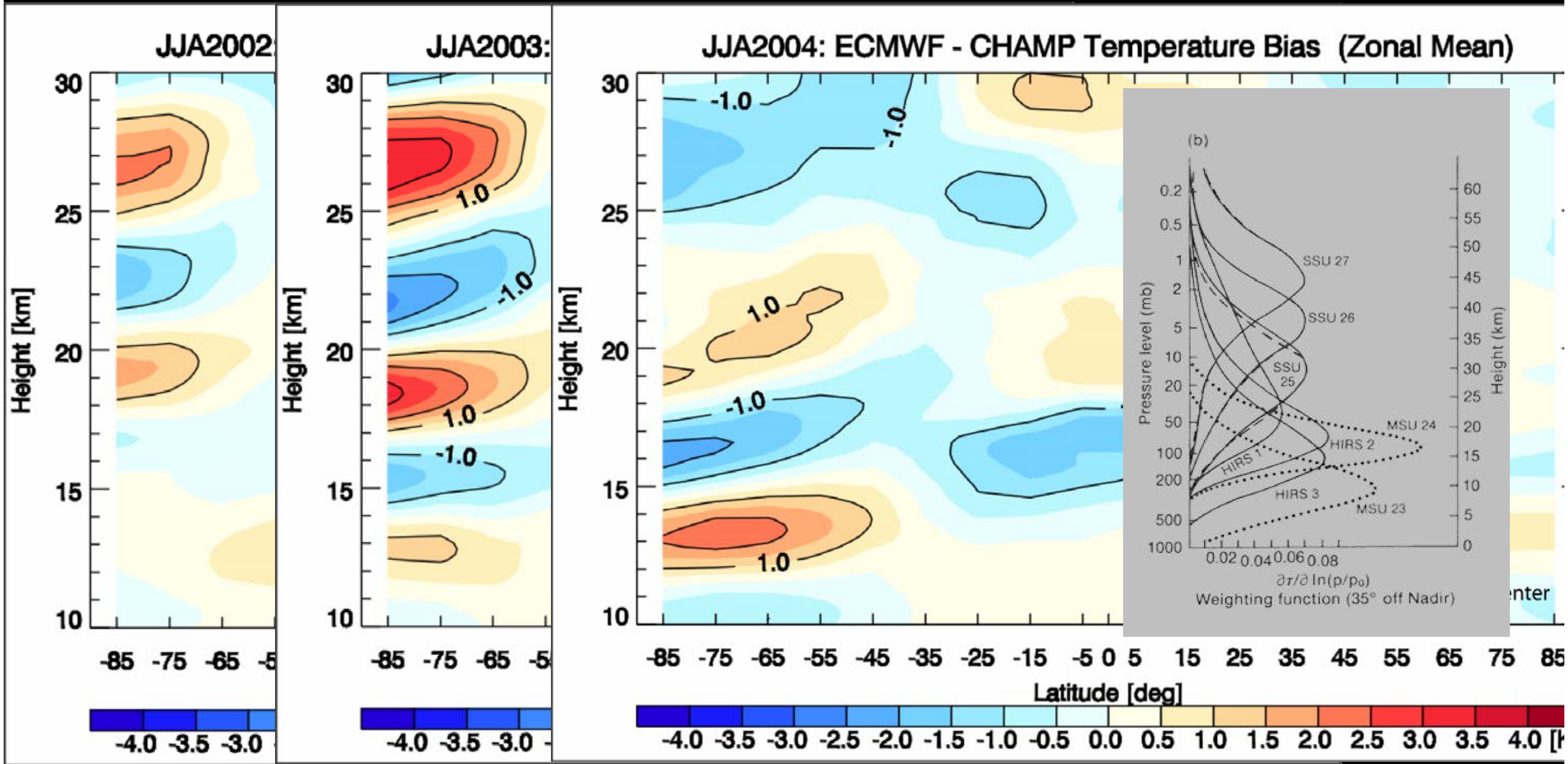
Wickert et al., 2005

Can we identify weaknesses of meteorological analyses by GPS radio occultation?

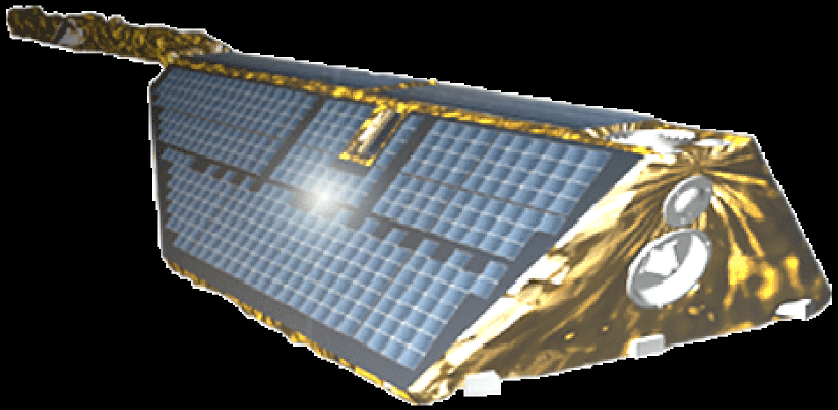
Yes!

ECMWF – CHAMP Seasonal Zonal Bias

Polar vortex bias

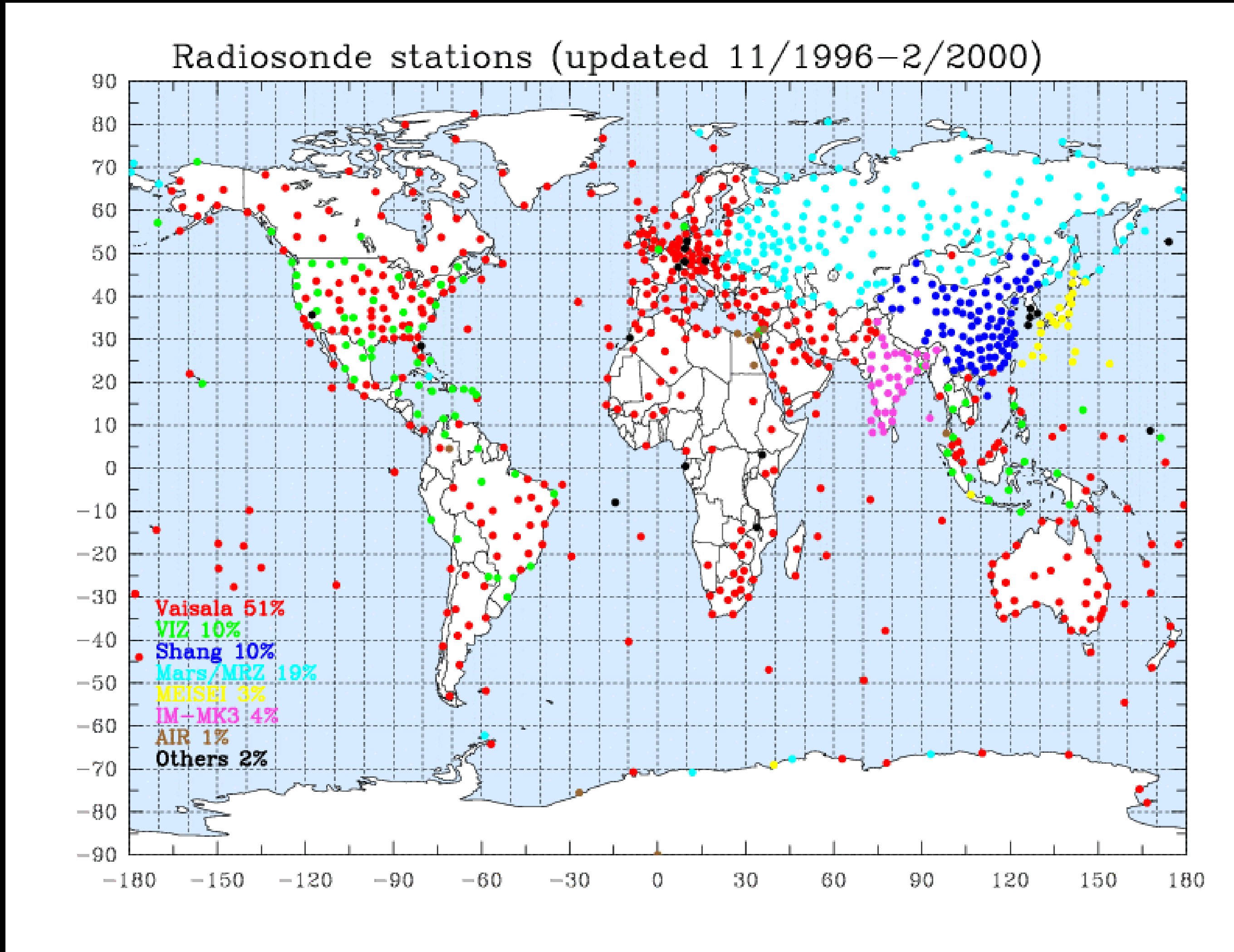


Gobiet et al., GRL, 2005



CHAMP vs. radiosonde

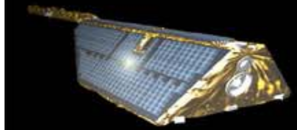
radiosonde = radiosonde?



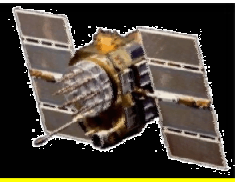
Kuo et al., GRL 2005

Can we identify differences between different types of RS by GPS radio occultation?

Yes!



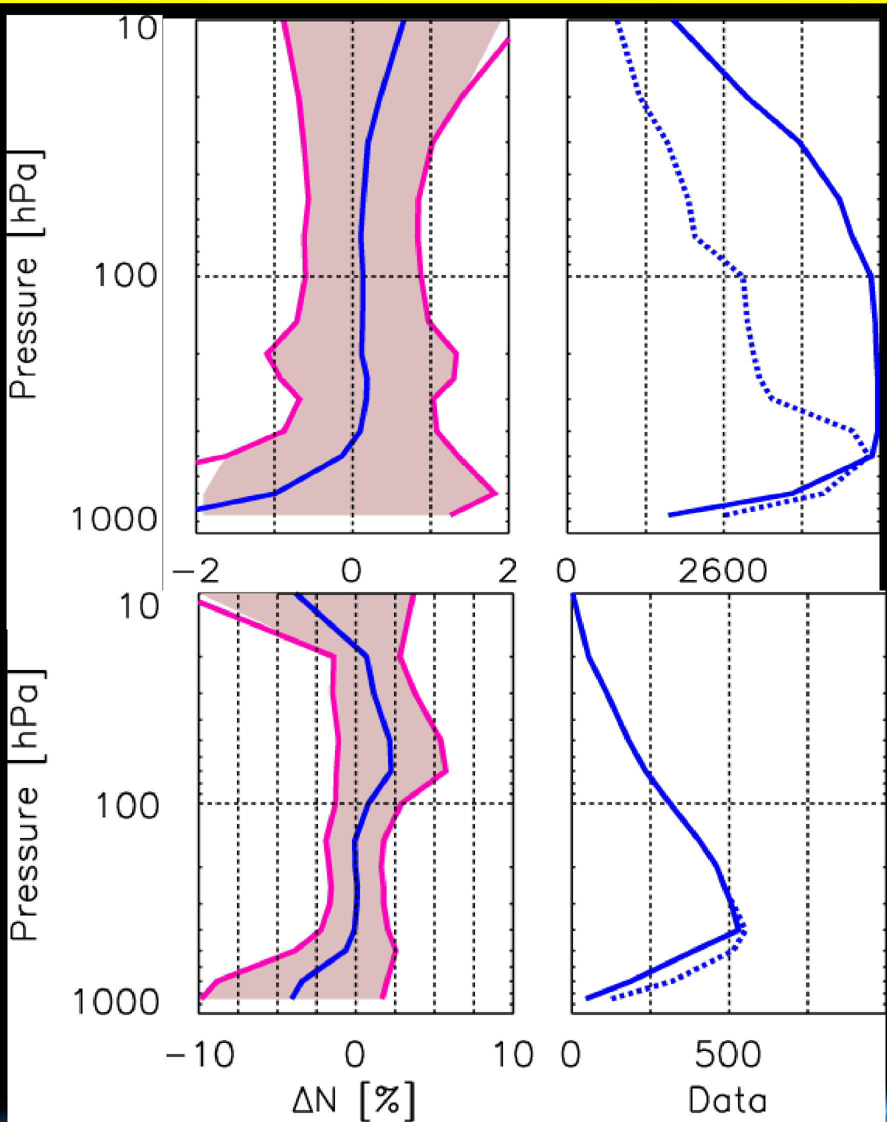
RS data availabiliy



Region	Prof.	100 hPa [%]	100 hPa WVP [%]	10 hPa [%]	10 hPa WVP [%]
Australia	813	98,03	13,78	18.45	16.48
China	2344	94,99	21,70	14,76	2.61
Europe	5153	97,88	56,59	34,06	15.97
Former SU	3093	87,50	74,58	10,78	8.41
India	552	56,52	0.18	0.36	0.00
Japan	586	100	0.00	65,01	0.00
U.S.	5694	97,17	95.99	72,84	71,38

RS Data availability is a problem

Differences of RS data quality



Europe: Vaisala

India:

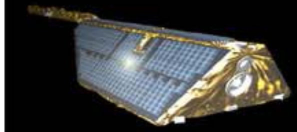
IM-MK3

Scale!

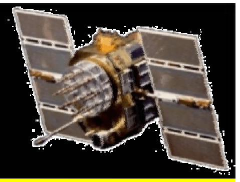
Wickert, 2005

CHAMP-RS

GFZ POTSDAM



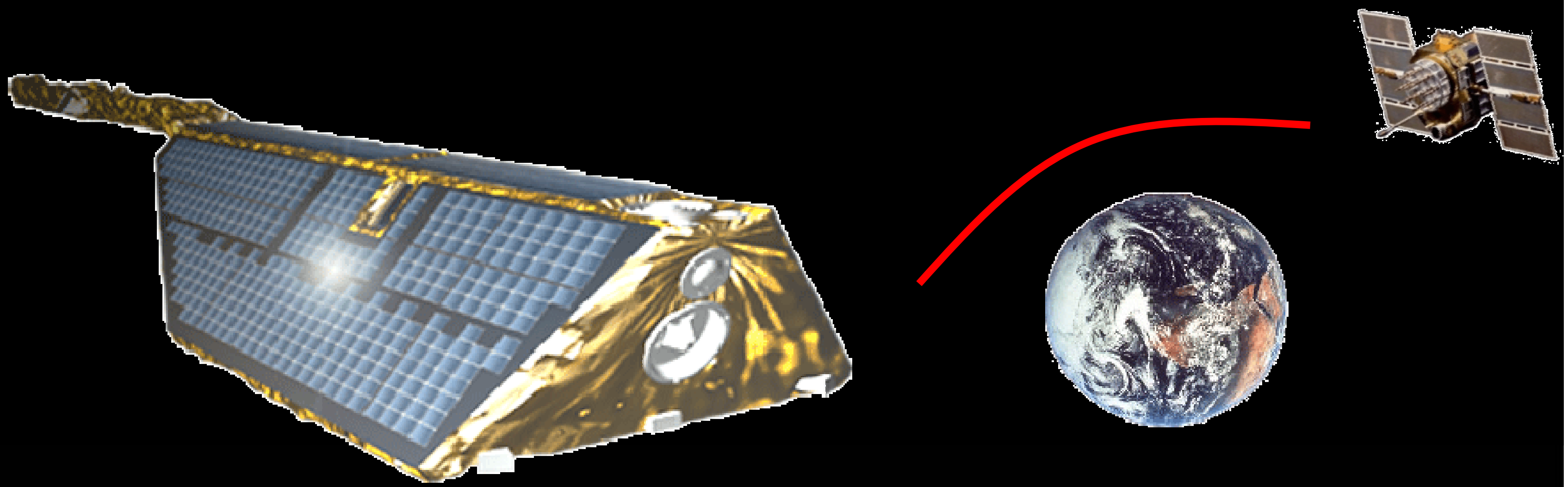
CHAMP-RS, 100 hPa (~10 km)



Region	No. (N)	ΔN[%]	$\sigma_{\Delta N}$ [%]
Australia	112	0.35	1.02
China	507	0.16	0.85
Europe	2916	0.13	0.73
Former SU	2297	0.07	0.74
India	1 (312)	-0.94 (0.79)	n.a. (2.09)
Japan	n.a. (586)	n.a. (0.22)	n.a. (1.32)
U.S.	5466	0.03	0.88

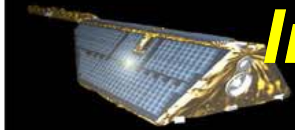
Very good agreement! (e.g. U.S.)

If WVP data were not available (n.a. the WVP data were set to 0 hPa above 300 hPa)

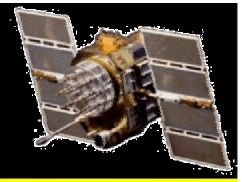


Applications

Weather forecast



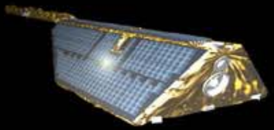
Improvement of global weather forecast with CHAMP



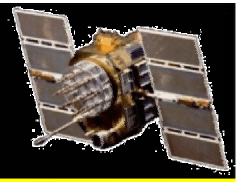
First promising impact studies for the use of CHAMP RO data to improve global weather predictions at UKMO and ECMWF: more from Sean

Good news: German Ministry for Science and Research will fund a project, which is aimed to the provision of near real time data from CHAMP with average delay of 2 and less hours between measurement and data provision

Climate



CHAMPCLIM (Wegcenter Graz, GFZ)



Global Climatologies – Two Modes

Direct climatology
(RO only)

3D-Var Analysis
(RO Refractivity + ECMWF)

Refractivity | **Temperature** | **Geopotential** | **Humidity**

Monthly | **Seasonal** | **Yearly**

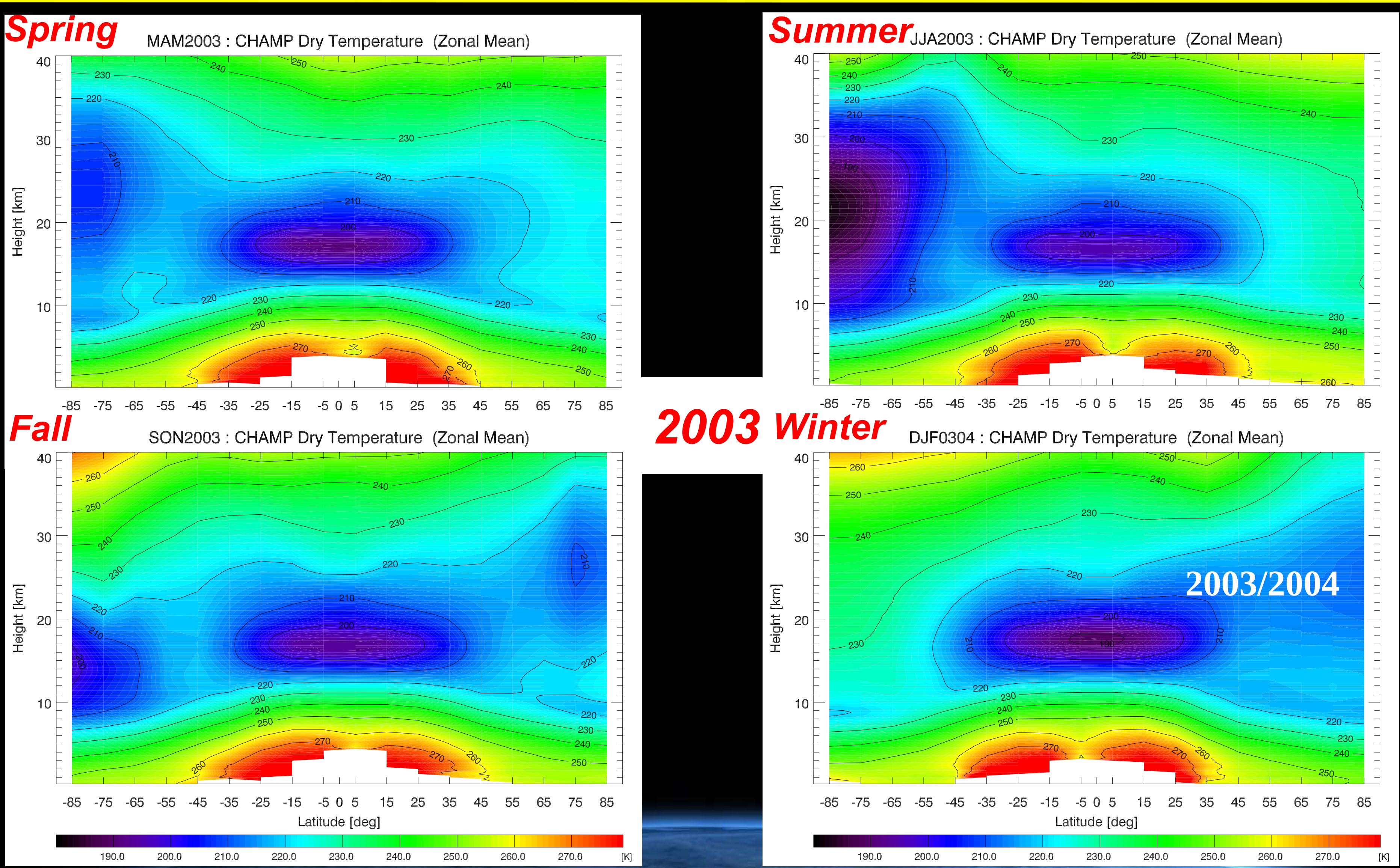
CHAMPCLIM Primary Products

CHAMPCLIM Special Products

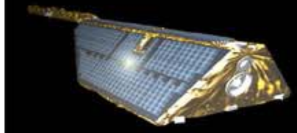
Tropopause Height, Tropopause Temperature, trends (future goal), ...

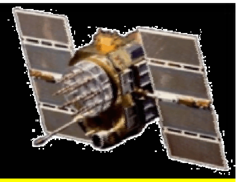
Foelsche et al., 2005

Seasonal T_{dry} Climatologies (direct)



Foelsche et al., 2005





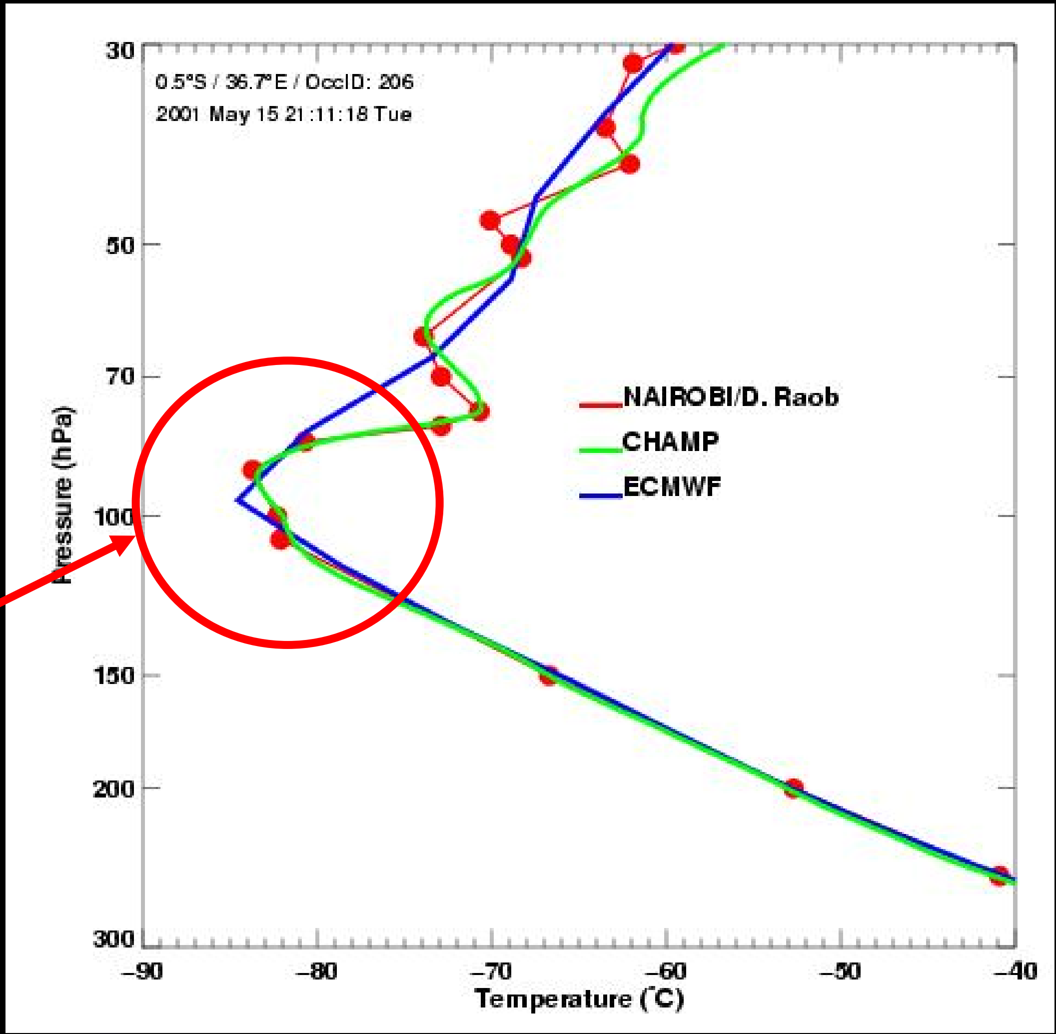
Climate: Tropopause

GFZ POTSDAM

Tropopause

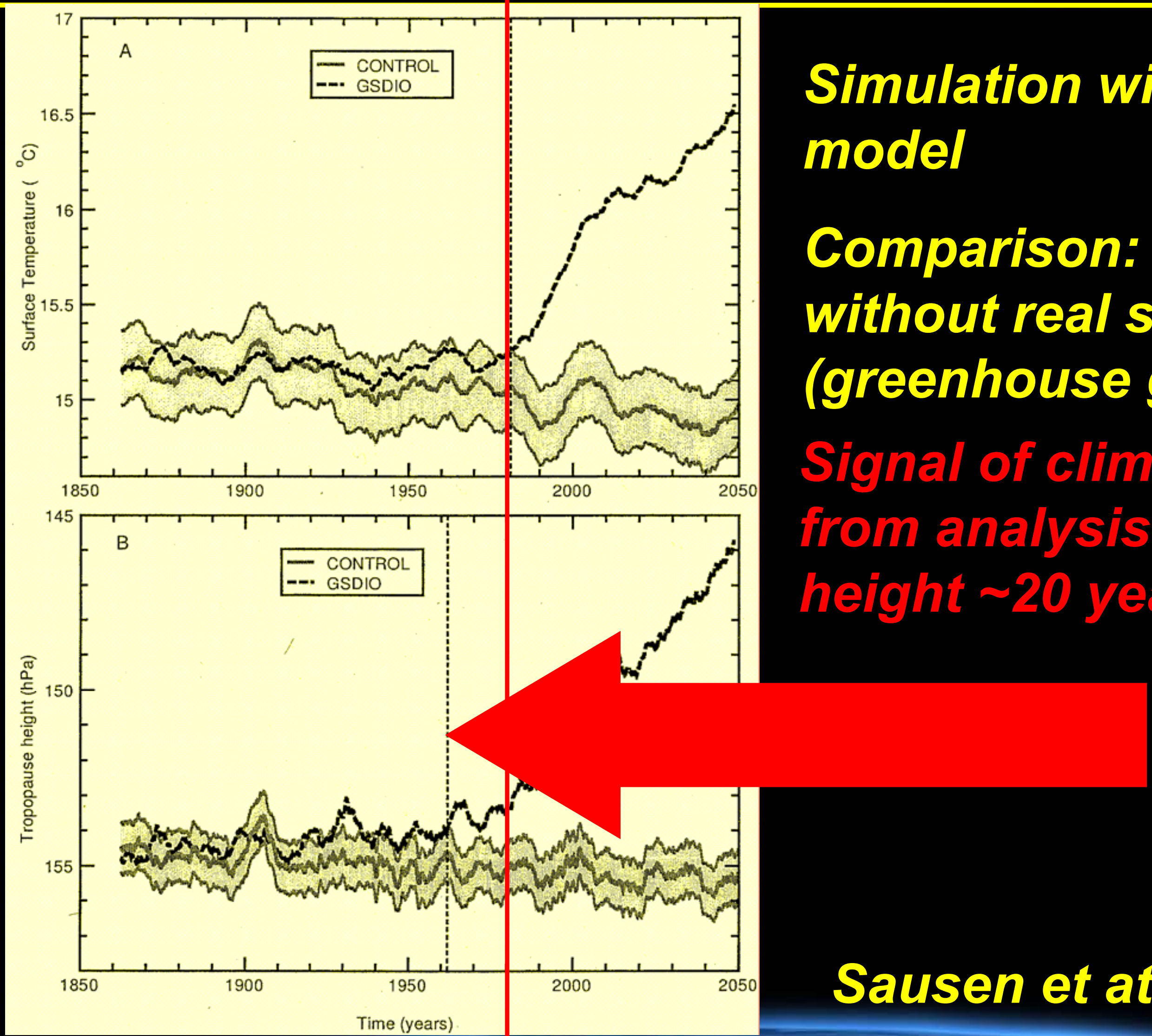
Temperature and altitude is indicator for climate change (Warming of the troposphere, cooling in the stratosphäre)

Tropopause



GFZ POTSDAM

Tropopause height and climate change



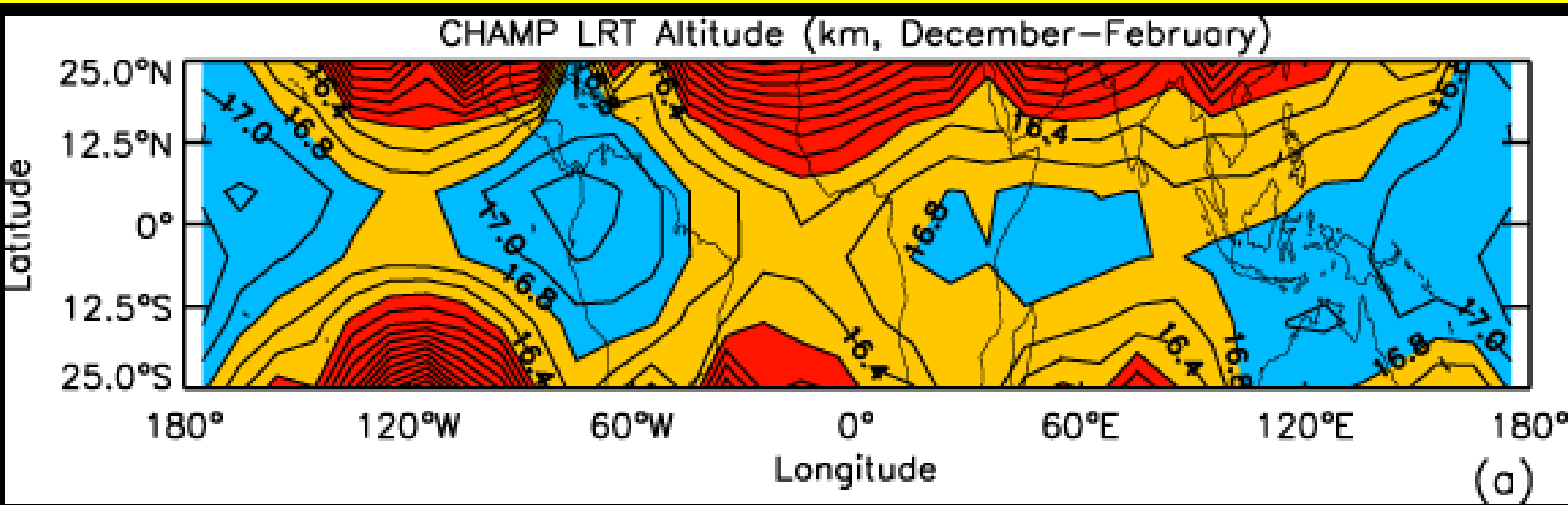
Simulation with climate model

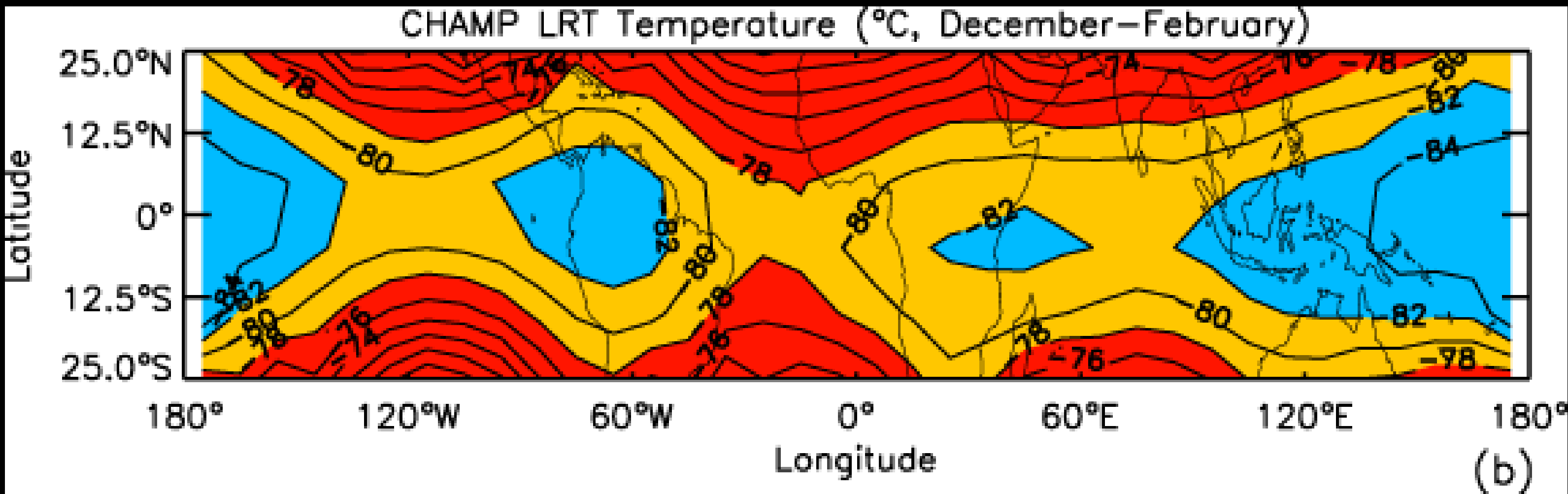
Comparison: with and without real scenario (greenhouse gases)

Signal of climate change by from analysis of tropopause height ~20 years earlier

Sausen et at., 2003

2001-2004/LRT T and h (Schmidt et al.)



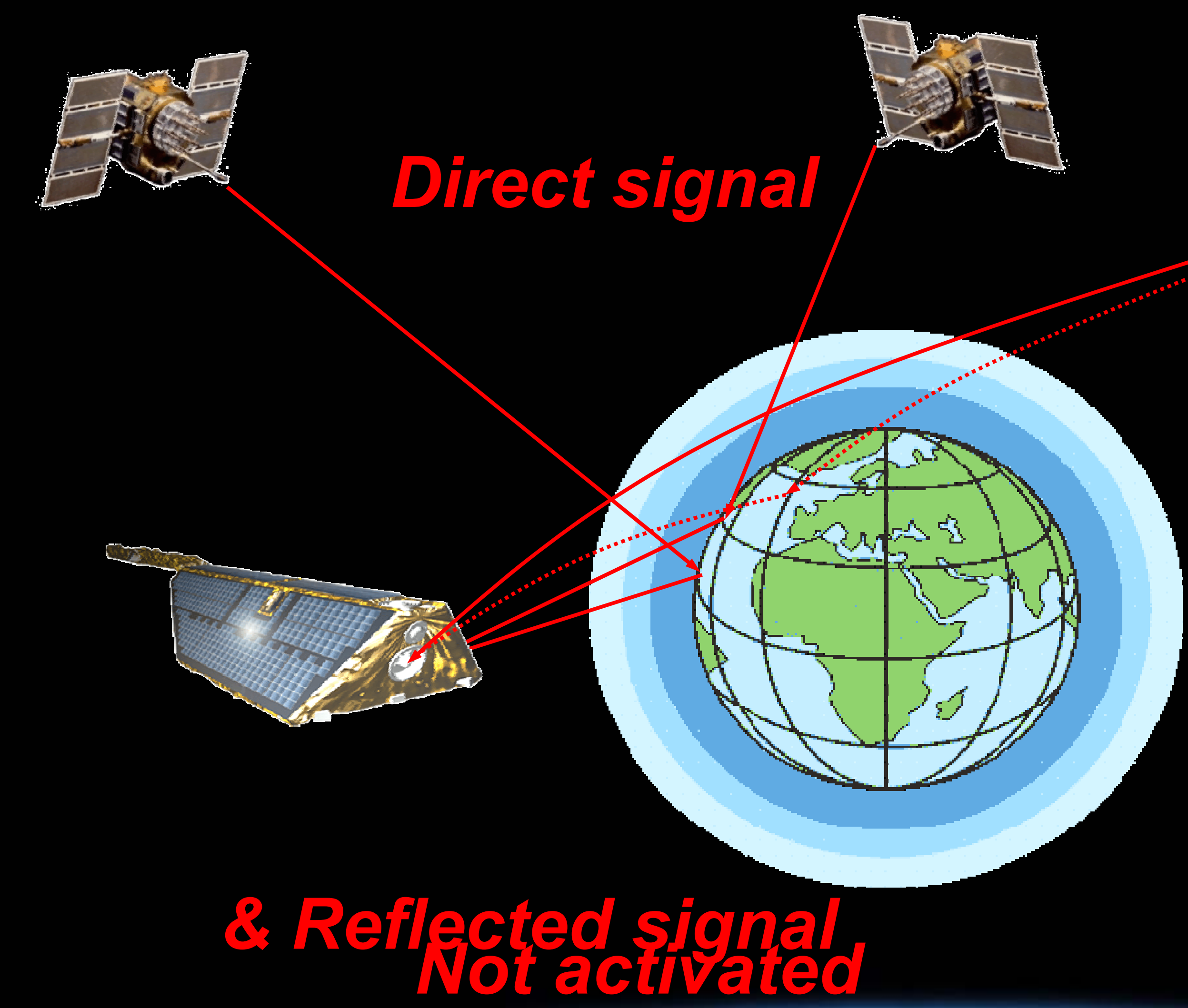


Tropopause characteristics Tropis (Trend)

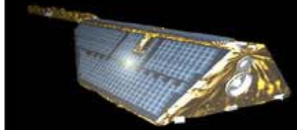
Per Dekade, CHAMP extrapolated (Attention!: only 3 years, in principle not allowed!)

	CHAMP (GFZ)	Seidel et al. (2001) RS 78-97	Santer et al. (2003) NCEP 78-97	Randel et al. (2000) NCEP 79-97
Altitude (m)	25	20		
Pressure (hPa)	-0,5	-0,5	-0,68	-0,32
Temp (K)	-0,21	-0,5		

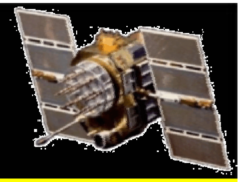
Reflections



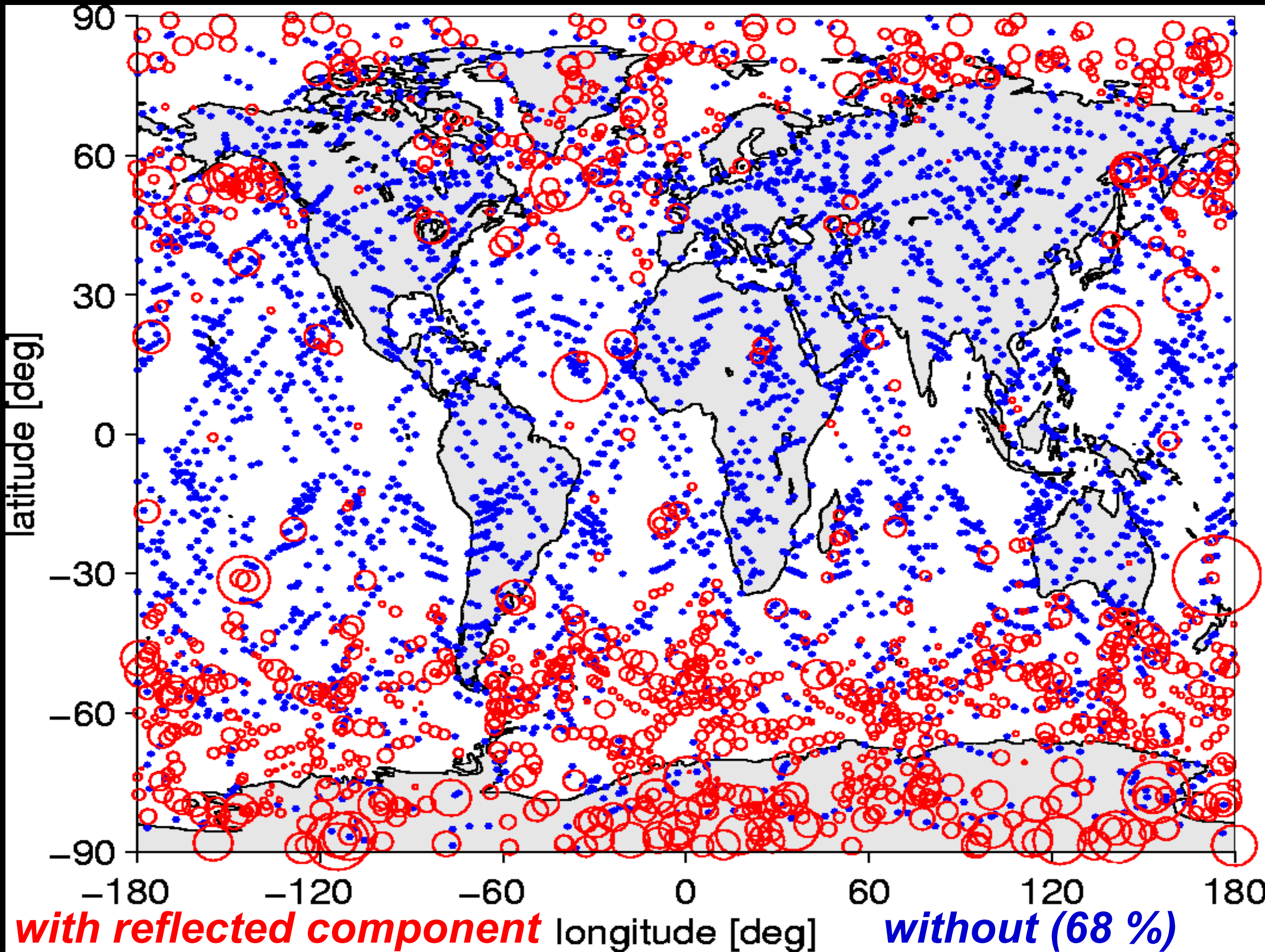
Occultation antenna (RHCP)



Reflexions



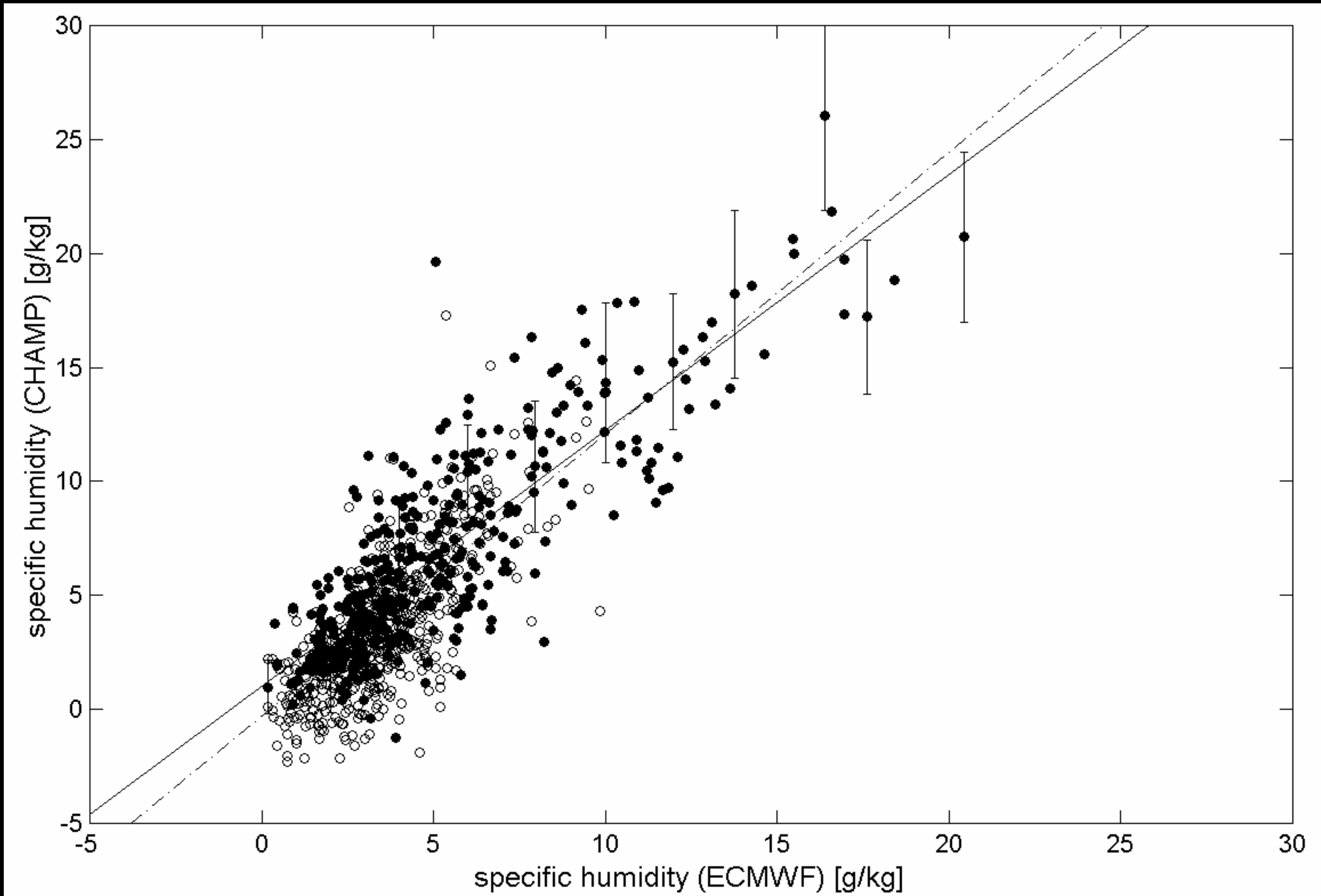
3783 occultation events observed between 14 May and 10 June 2001



Beyerle et al., JGR, 2002

Reflections

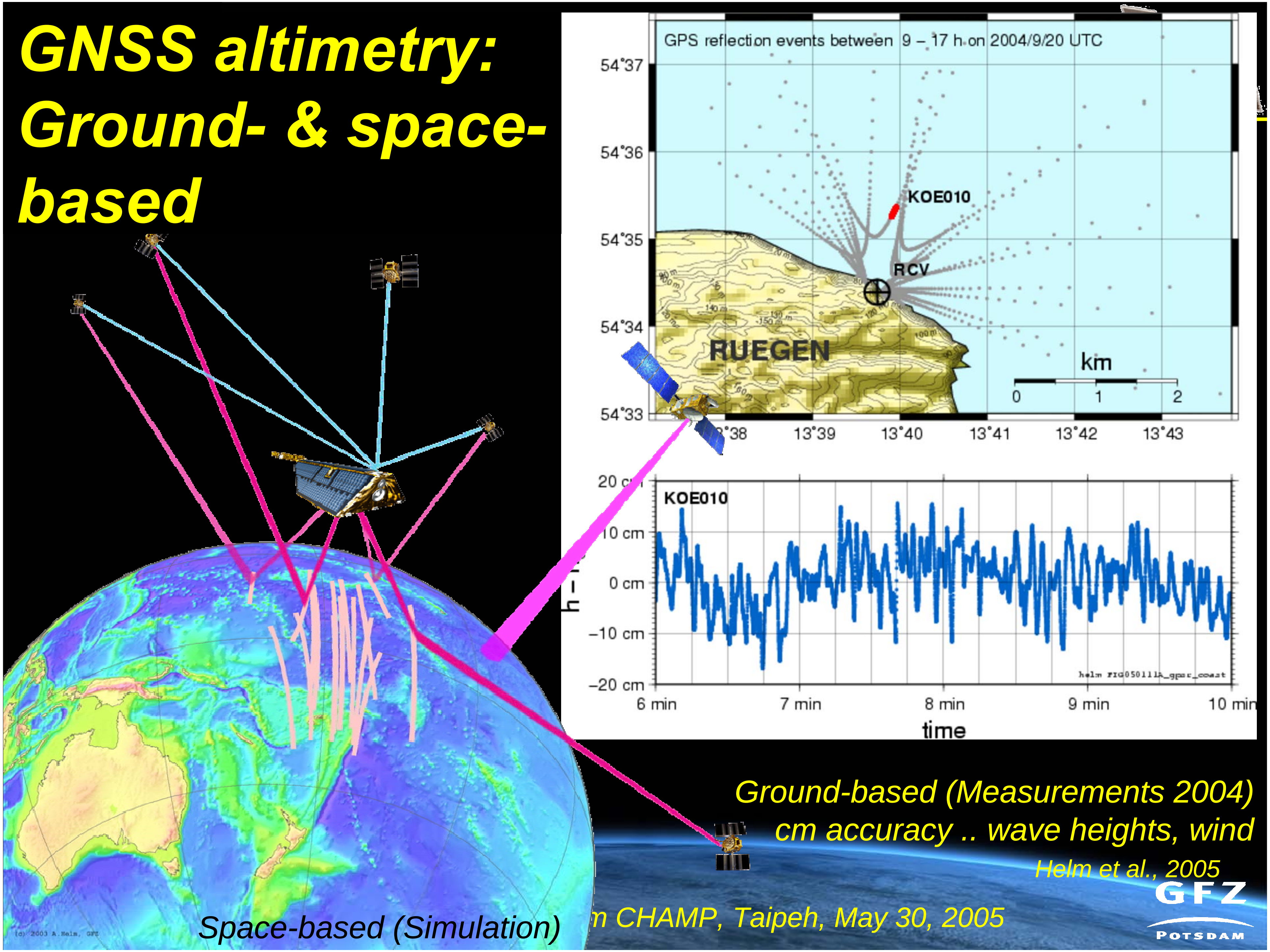
Specific humidity at the reflection point compared with ECMWF



Beyerle et al., JGR, 2002

GFZ POTSDAM

GNSS altimetry: Ground- & space-based



Ground-based (Measurements 2004)
cm accuracy .. wave heights, wind
Helm et al., 2005

Space-based (Simulation)

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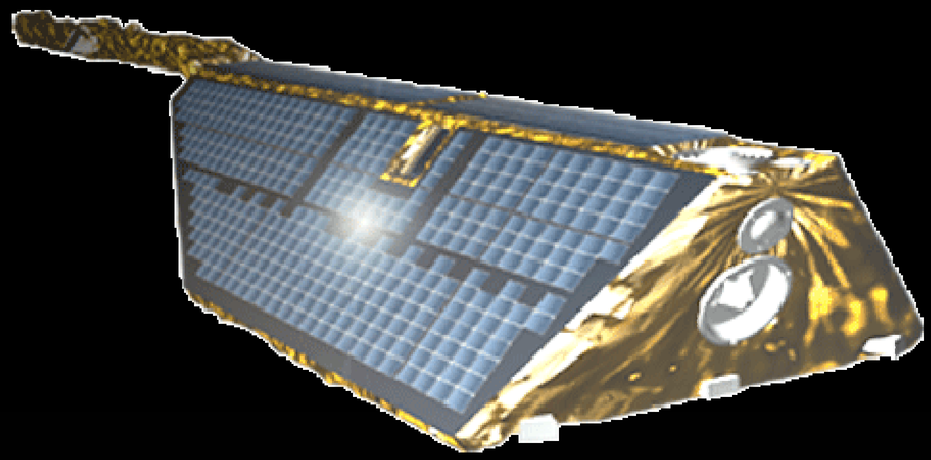
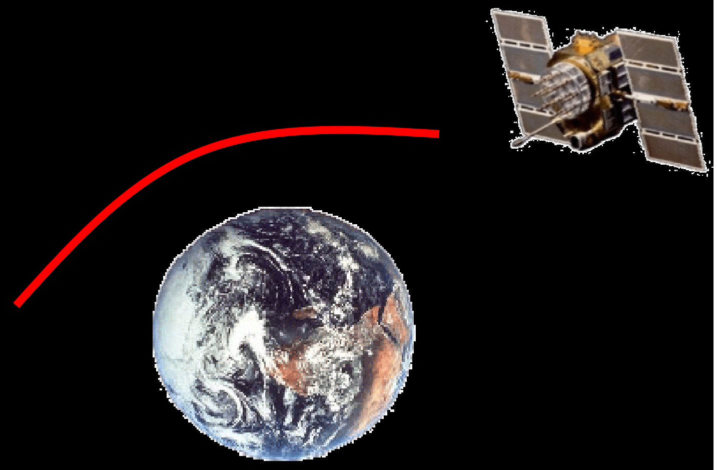
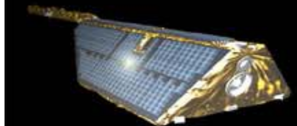
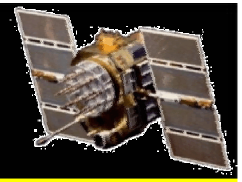




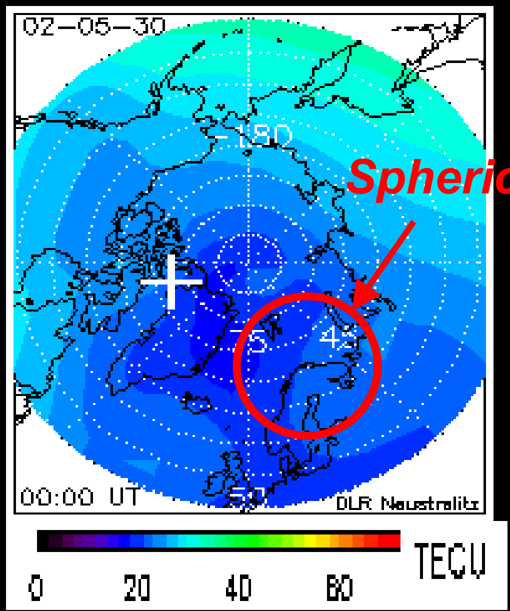
Ionosphere

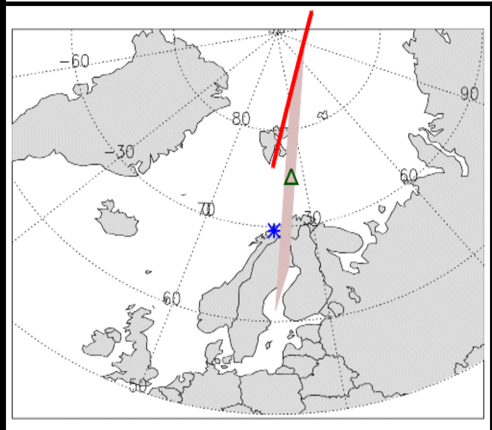


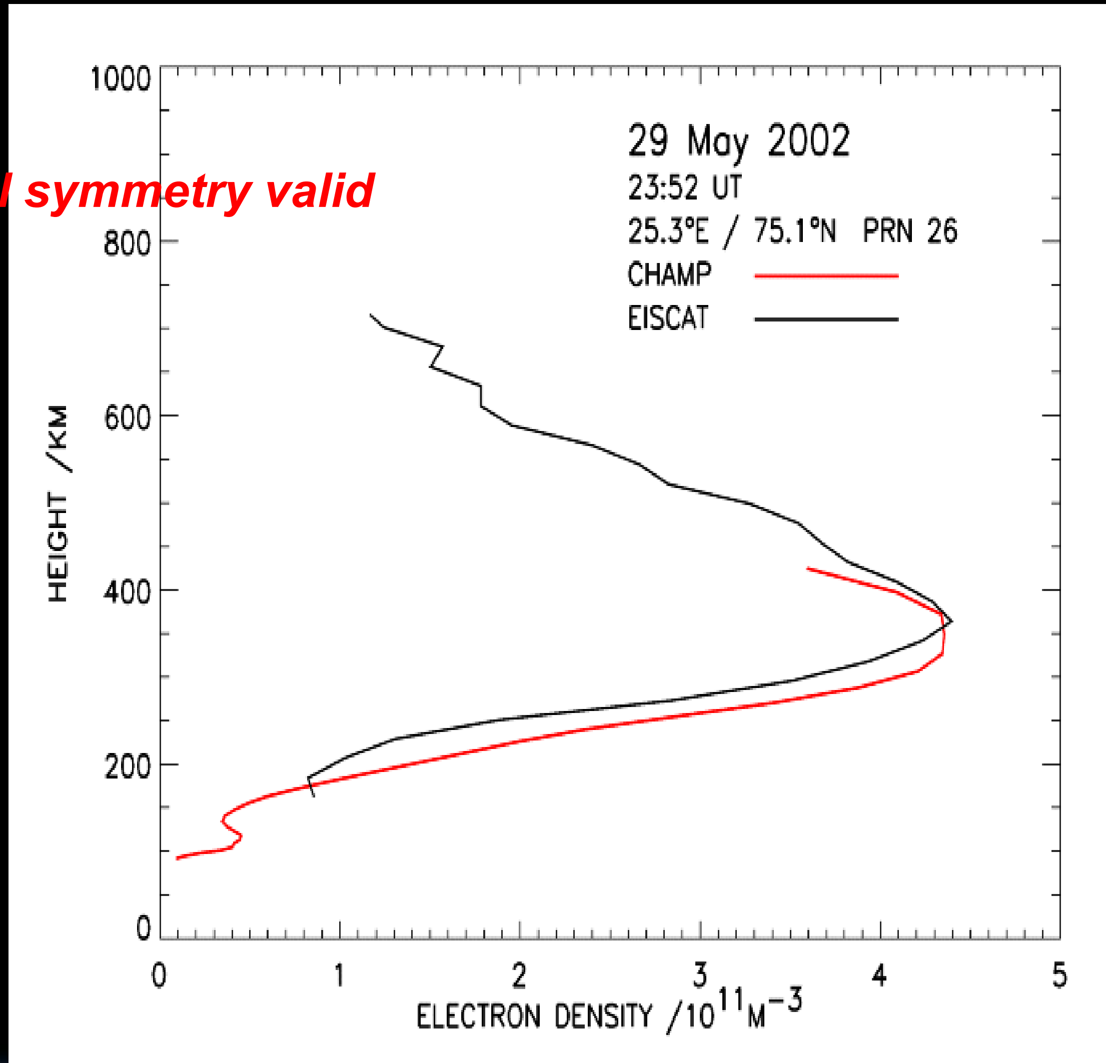
Validation: CHAMP vs. EISCAT



Spherical symmetry valid

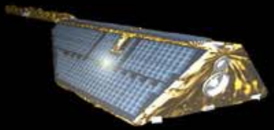


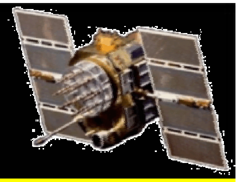


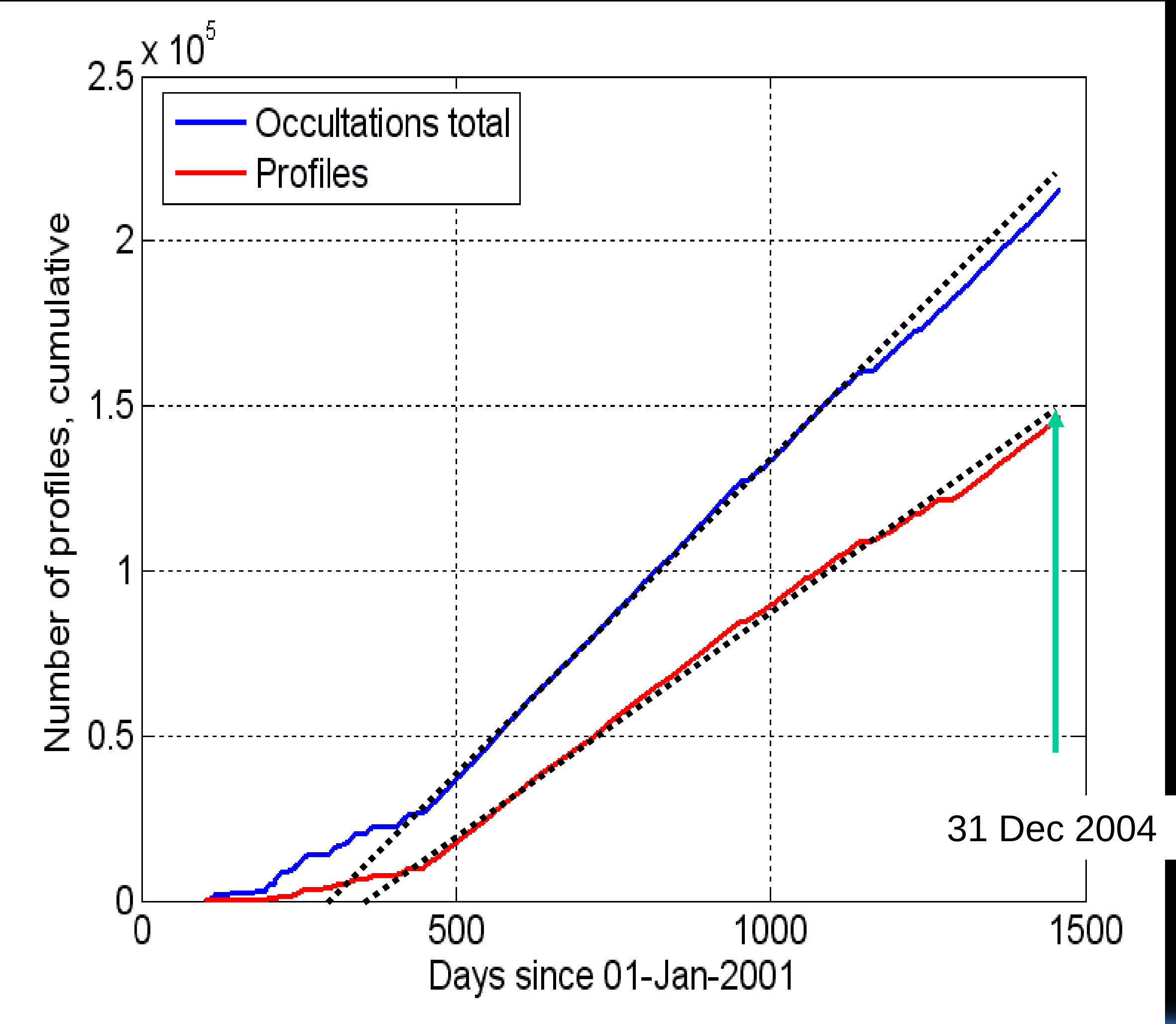


Stolle et al., 2004

CHAMP / IRO - Statistics





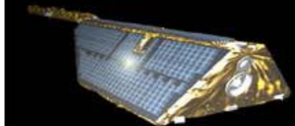


Jakowski et al., 2005

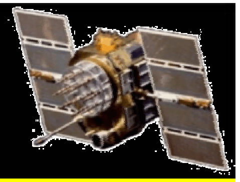
Ionospheric RO measurements from CHAMP are routinely processed at DLR/IKN Neustrelitz since April 11, 2001

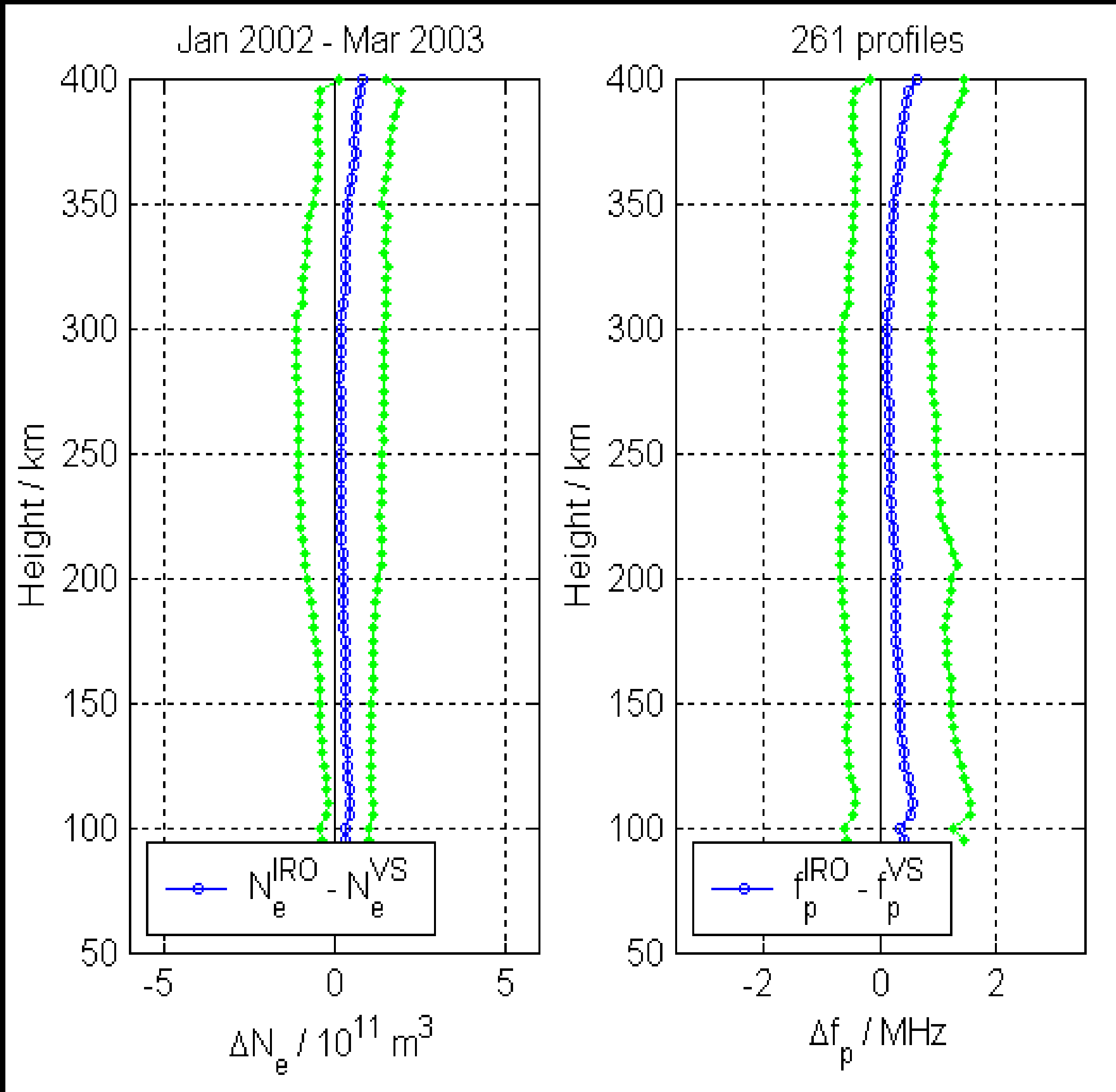
Time delay: 3 hours
About 200 occultations per day,
Up to 150 electron density profiles successfully derived per day:

> 200 000 measurements
≈ 150 000 profiles



Validation: CHAMP vs. Ionosondes





Comparison of entire IRO derived electron density profiles with corresponding vertical sounding measurements

Coincidence radius: 6 °
Time window: 15 min.
Ionosonde station:

Juliusruh (54.6°N; 13.4°E)

Number of profiles: 261
Bias < 0.8MHz (1 x$10^{11}$$m^{-3}$)
RMS ≅ 1 MHz
(≅ 1.2 x$10^{11}$$m^{-3}$)

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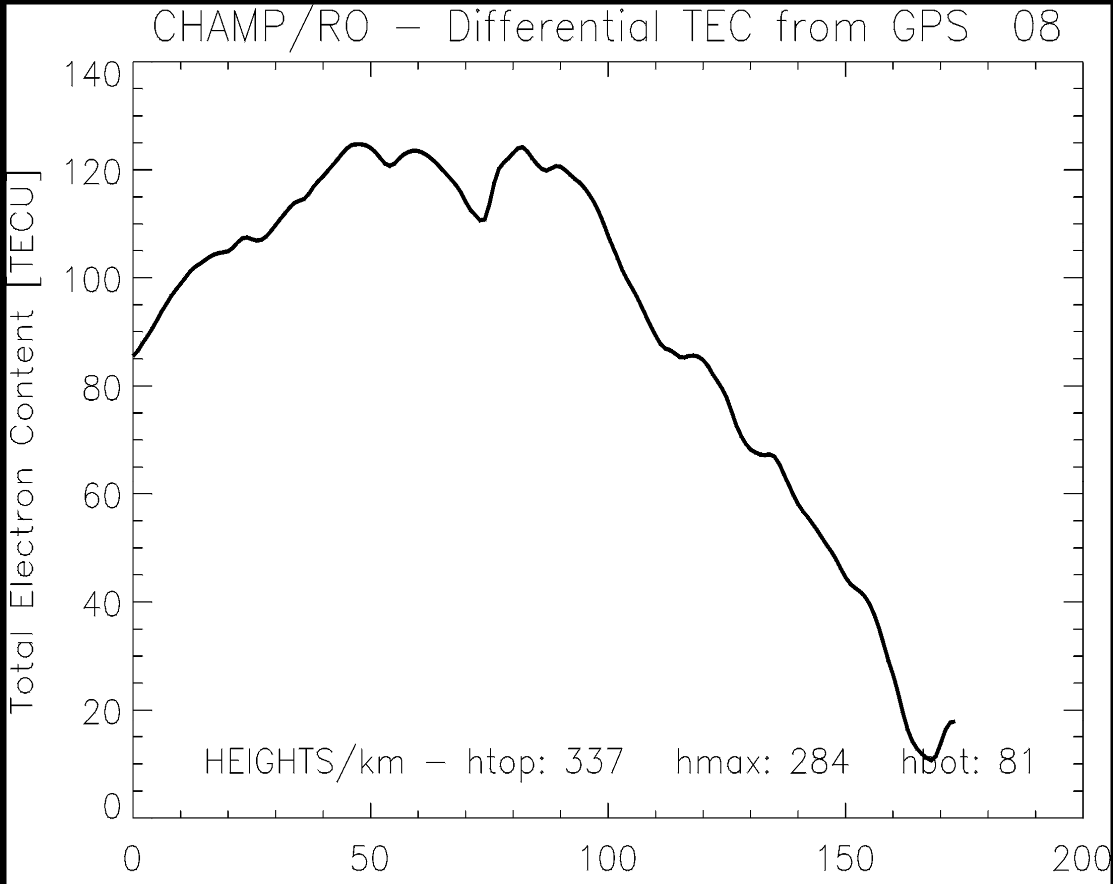
Detection of ionospheric perturbations

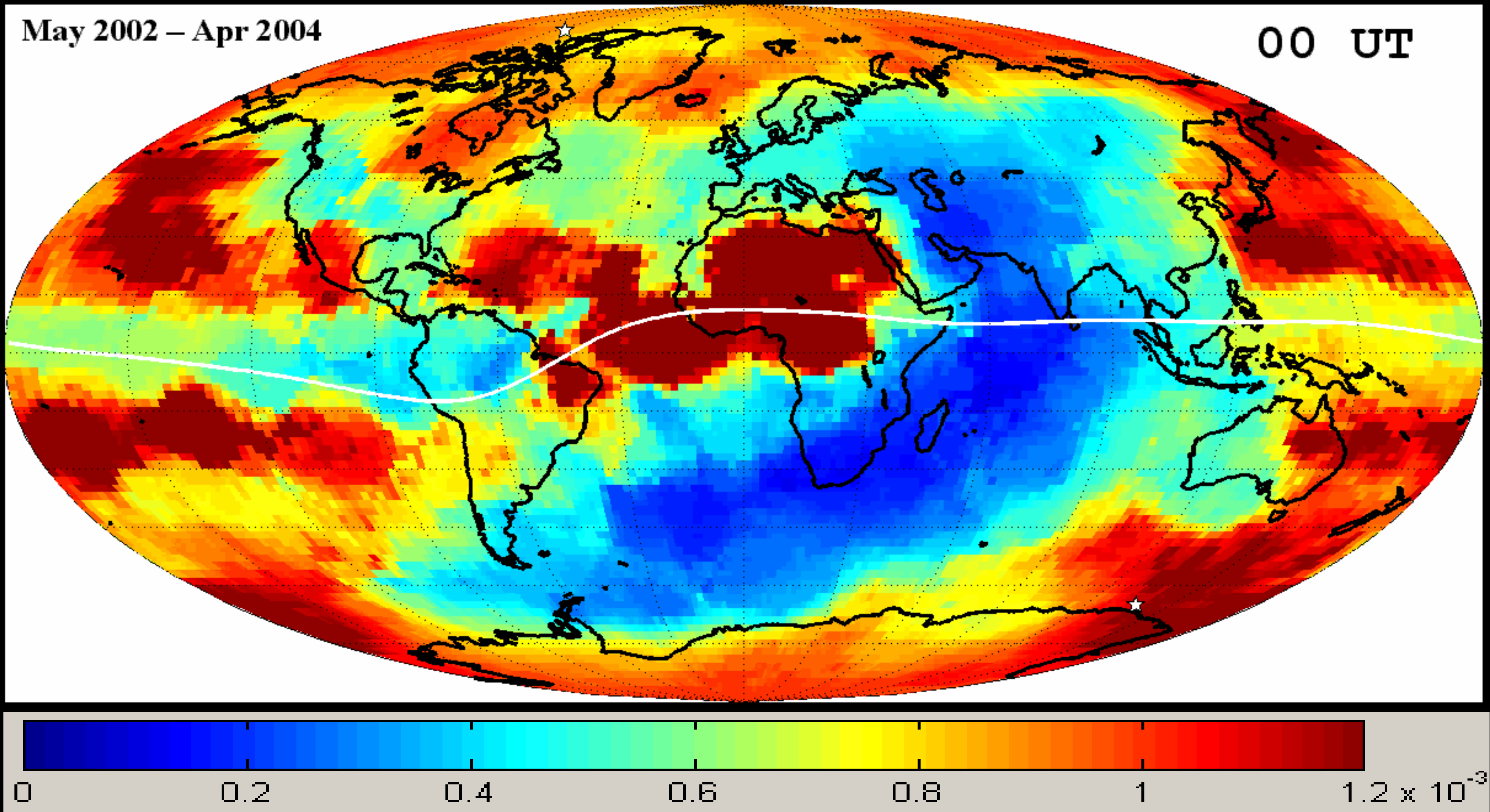


TID-measurements onboard CHAMP
doy: 165, 2001

Detection of TID structures and their analysis

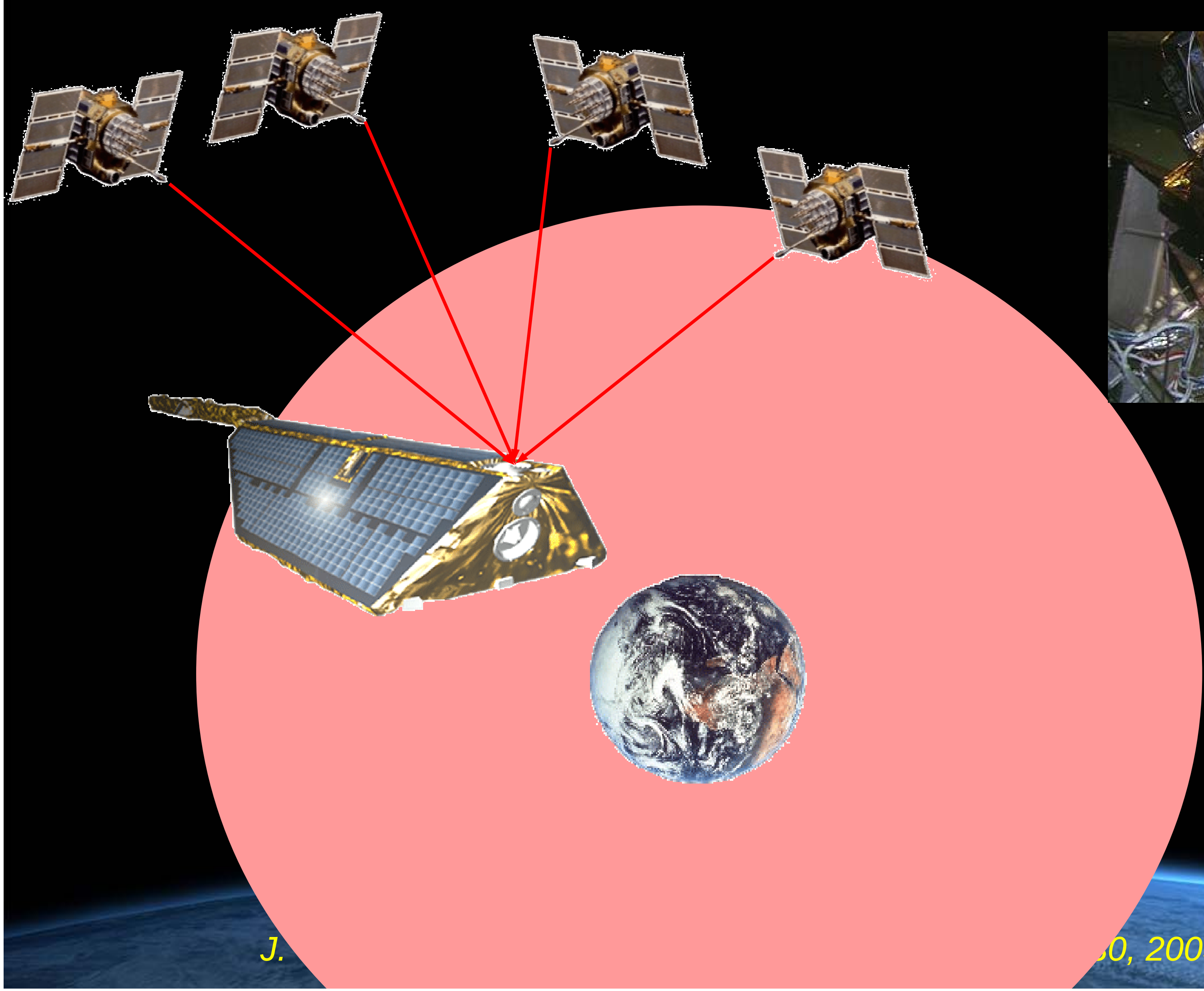
- *Indicate coupling processes between lower atmospheric layers and the Ionosphere*
- *TID's affect accuracy of high precision GNSS applications*

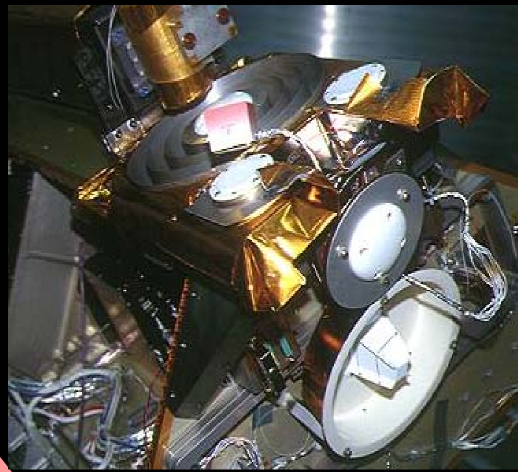
Ionospheric disturbance activity by IRO data (CHAMP)

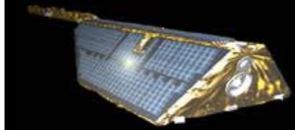


Investigation of ionospheric small / medium scale irregularities possible

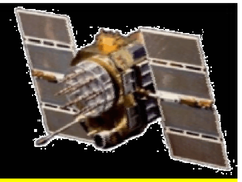
Topside ionospheric sounding



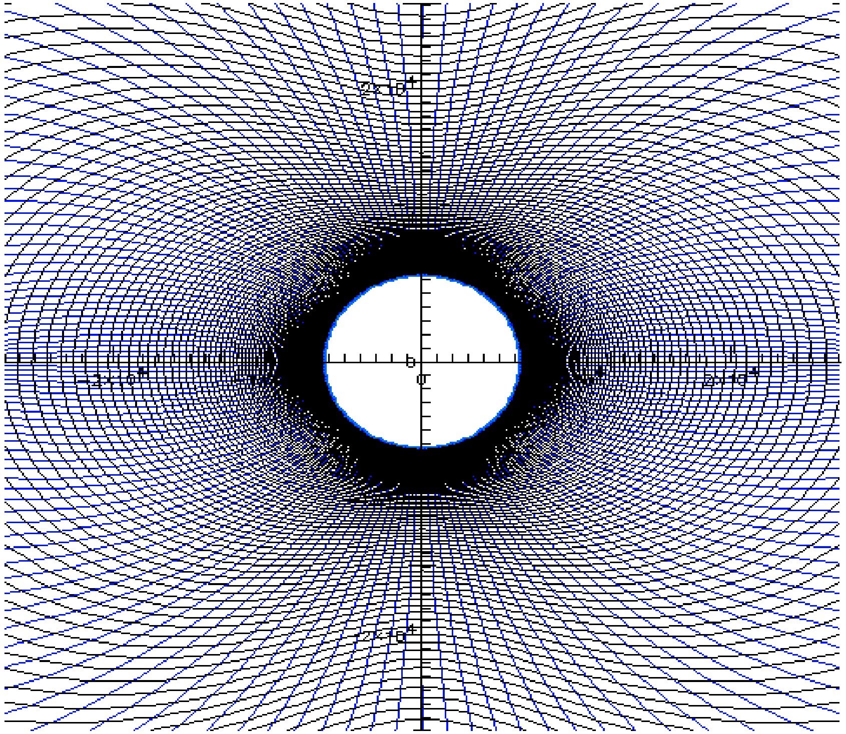


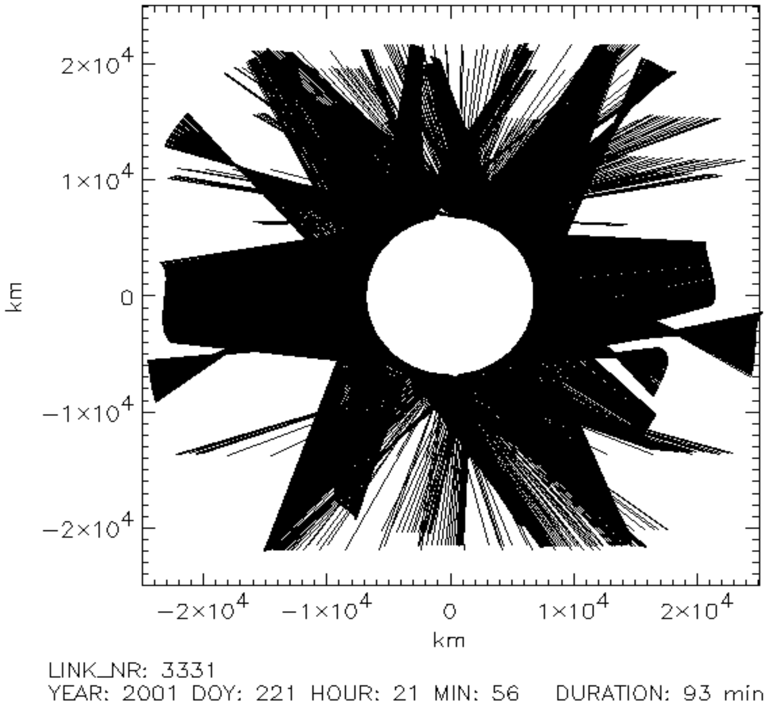


Topside ionosphere TEC assimilation



Voxel structure for data assimilation and 2D projection of a typical radio link distribution obtained after a full CHAMP revolution





Discretization for ray path j:

$$TEC_j = \sum_i n_{e\,ij}\, ds_{ij}$$

TEC = D*X

PIM → ↓

Electron density

$X \leftrightarrow n_{e\,ij}$ mean electron density in voxel [ij]

$D \leftrightarrow ds_{ij}$ ray path element within voxel [ij]

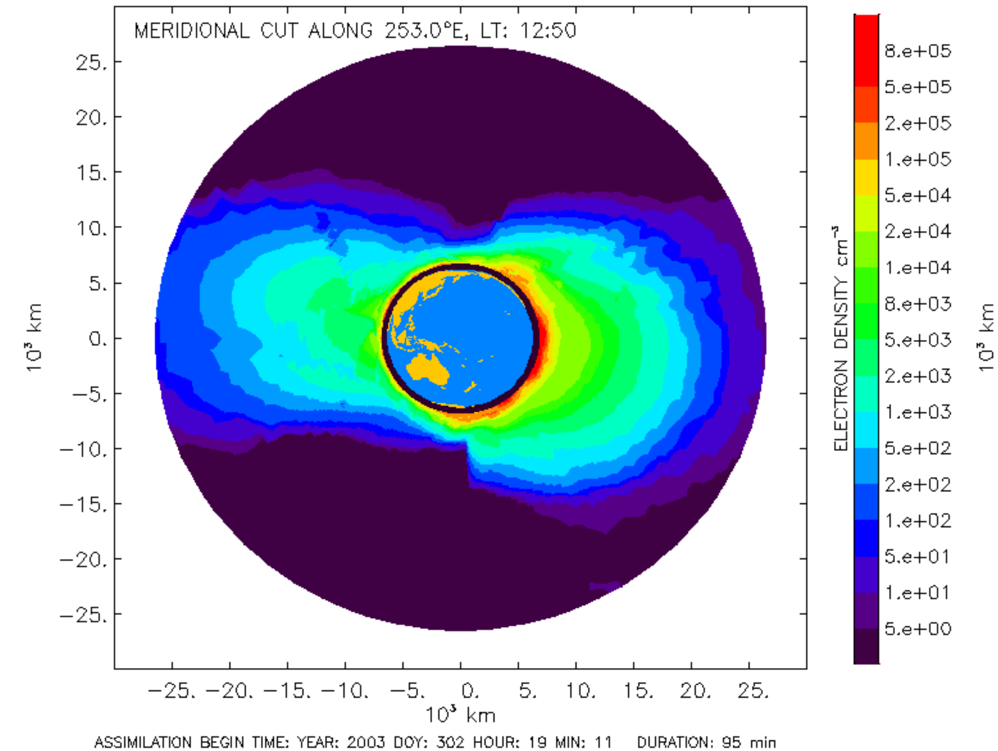
Heise, 2002

GFZ POTSDAM

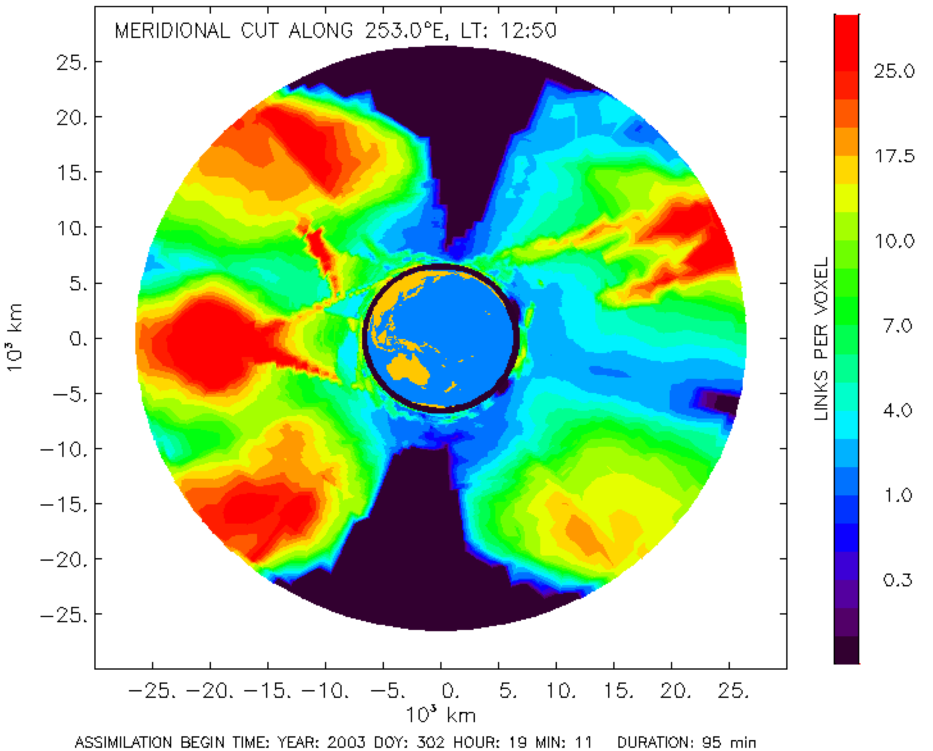
CHAMP topside ionosphere sounding

Assimilation example (meridional slice in orbit plane)
October 29, 2003, assimilation begin: 19:11 UT, duration: 95 min
(geomagnetic storm)

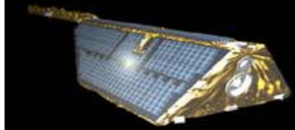
Electron density distribution



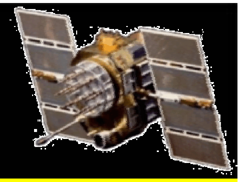
Data coverage



Heise et al., 2005



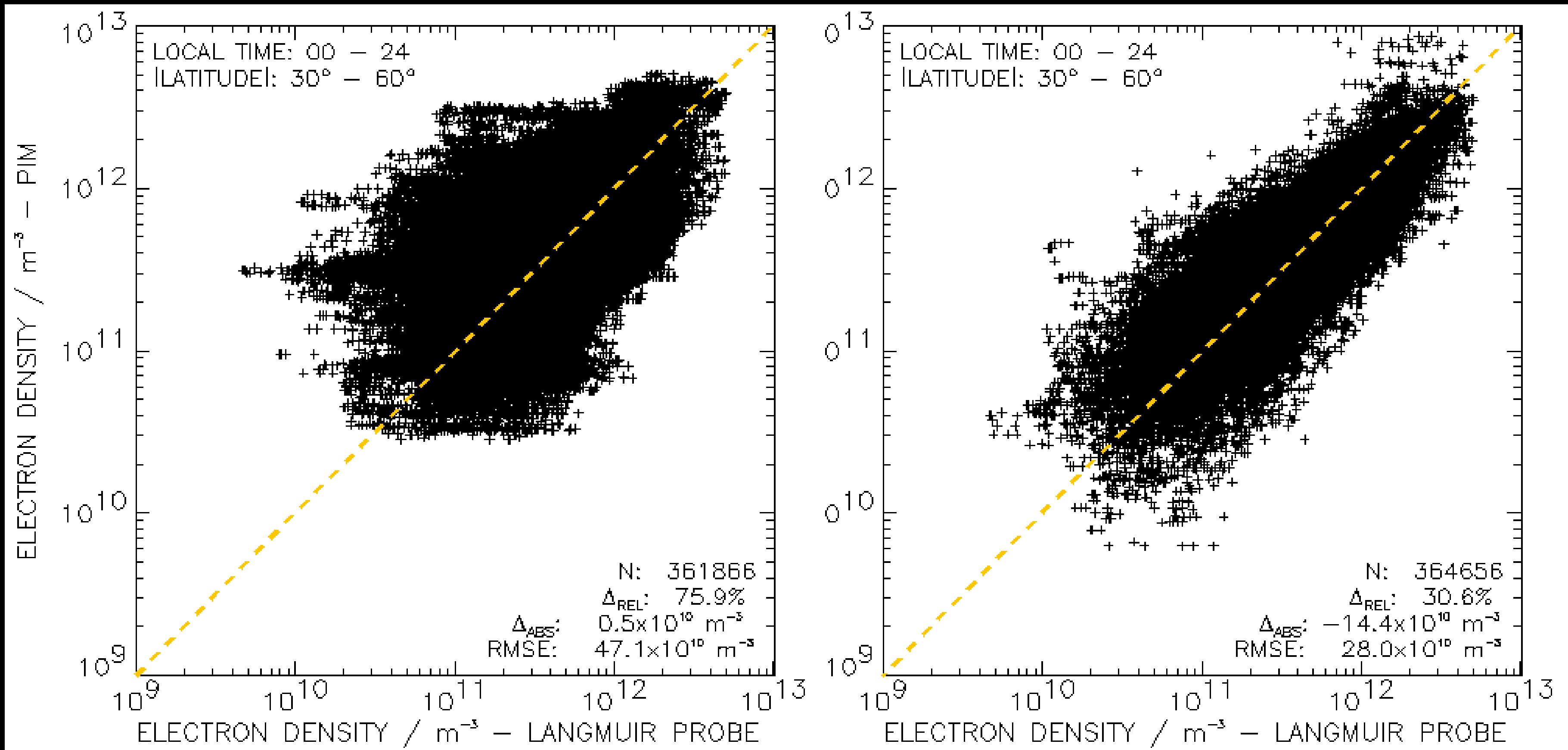
Validation Langmuir Probe

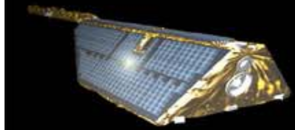


Scatter plots from 1 January to 10 May 2002, 30° < /φ/ < 60°

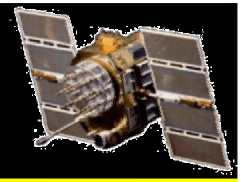
Langmuir Probe versus:

Initial model (PIM) | **assimilation results**

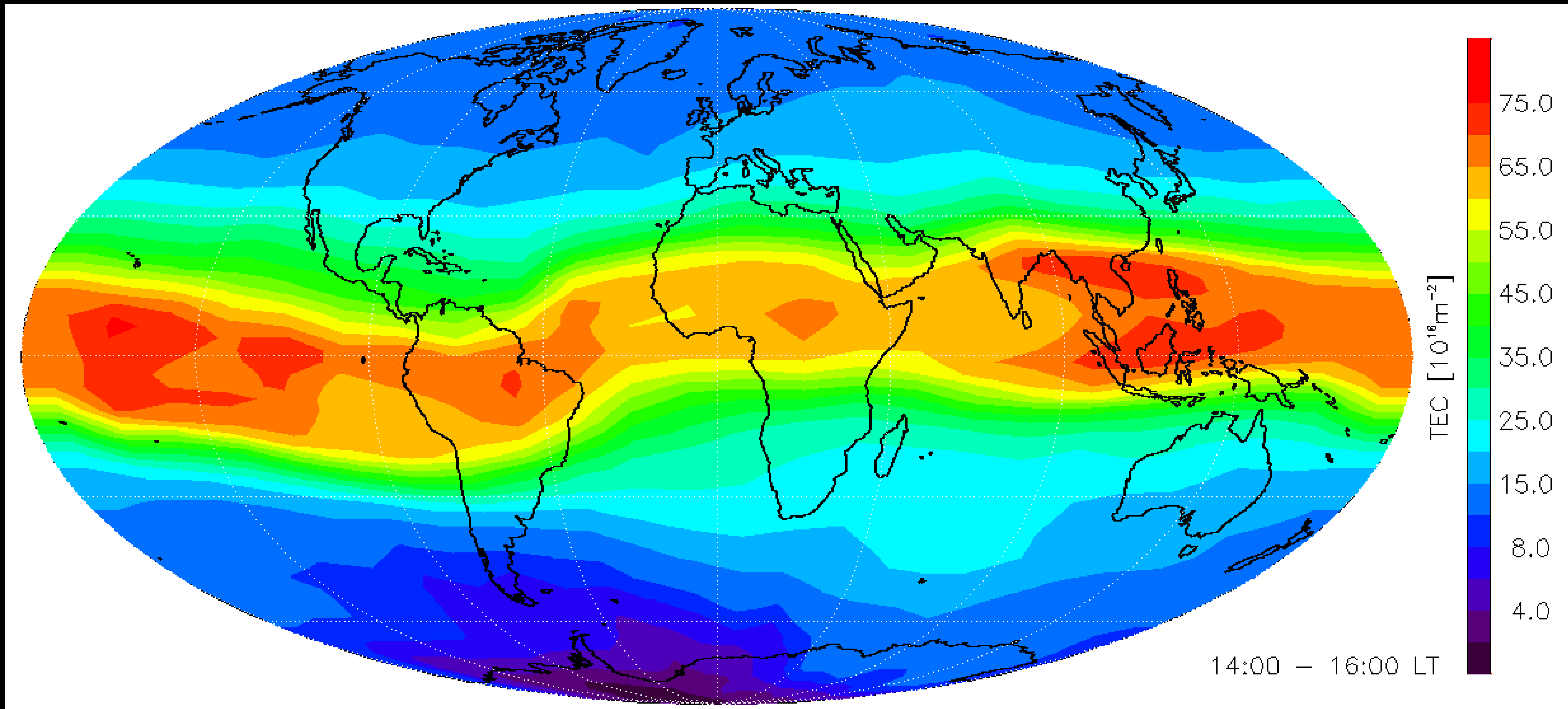




TEC above 450 km (Topside TEC)



14:00 – 16:00 local time, April 17 till May 07, 2002
Resolution: 2.5° lat x 15° lon



Data base:~*90.000 topside electron density profiles along CHAMP path*

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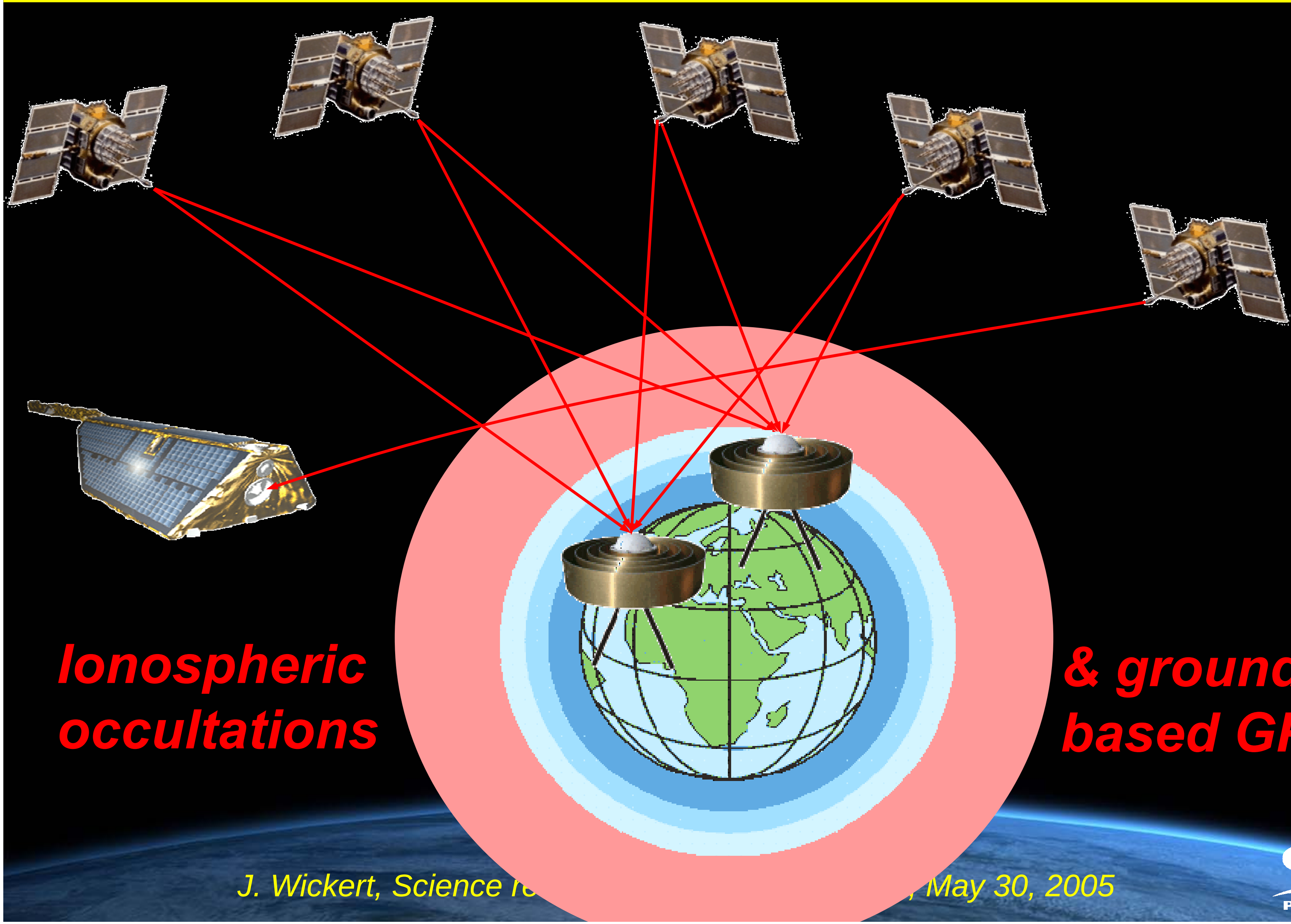
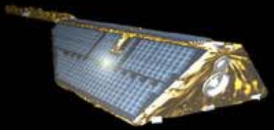
Ionospheric tomography

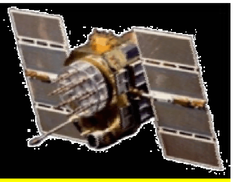


Ionospheric occultations

& ground based GPS

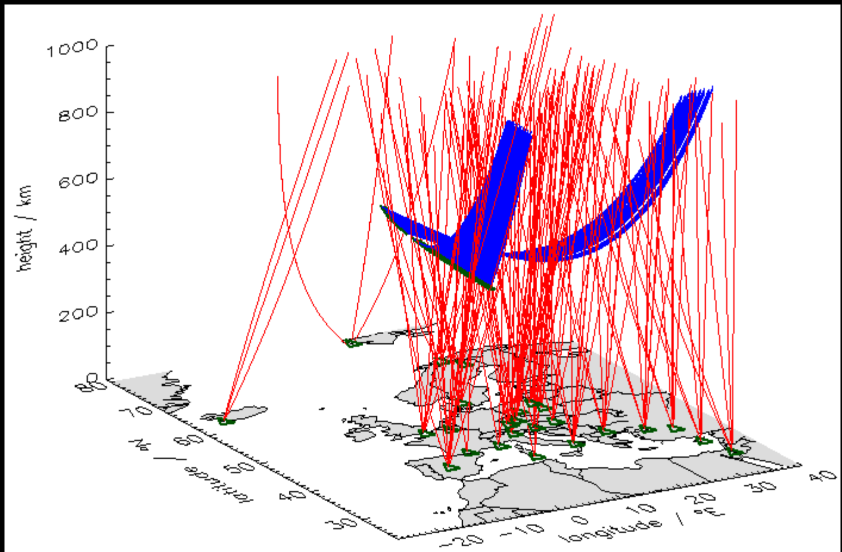


Assimilation procedure (to IRI/GCPM)



Application to:

Europe

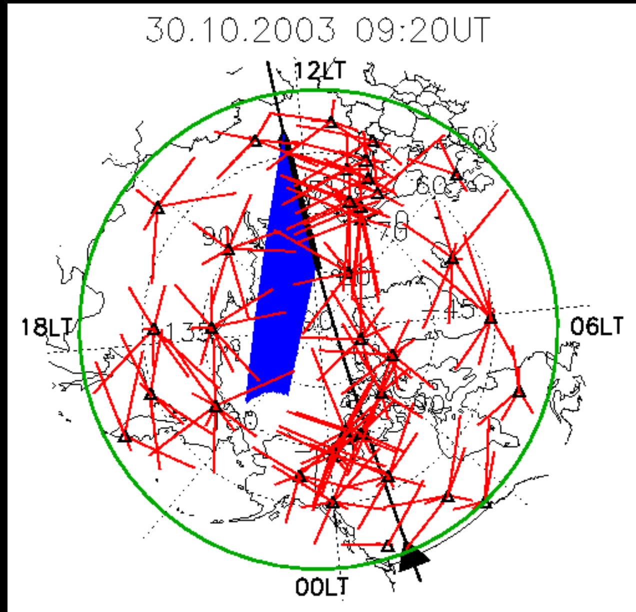


$$\Delta lon = 5°$$

$$\Delta lat = 2.5°$$

$$\Delta height = 10km$$

North polar region

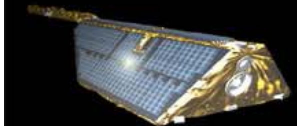


$$\Delta lon = 10°$$

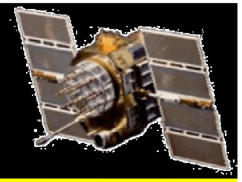
$$\Delta lat = 4°$$

$$\Delta height = 20km$$

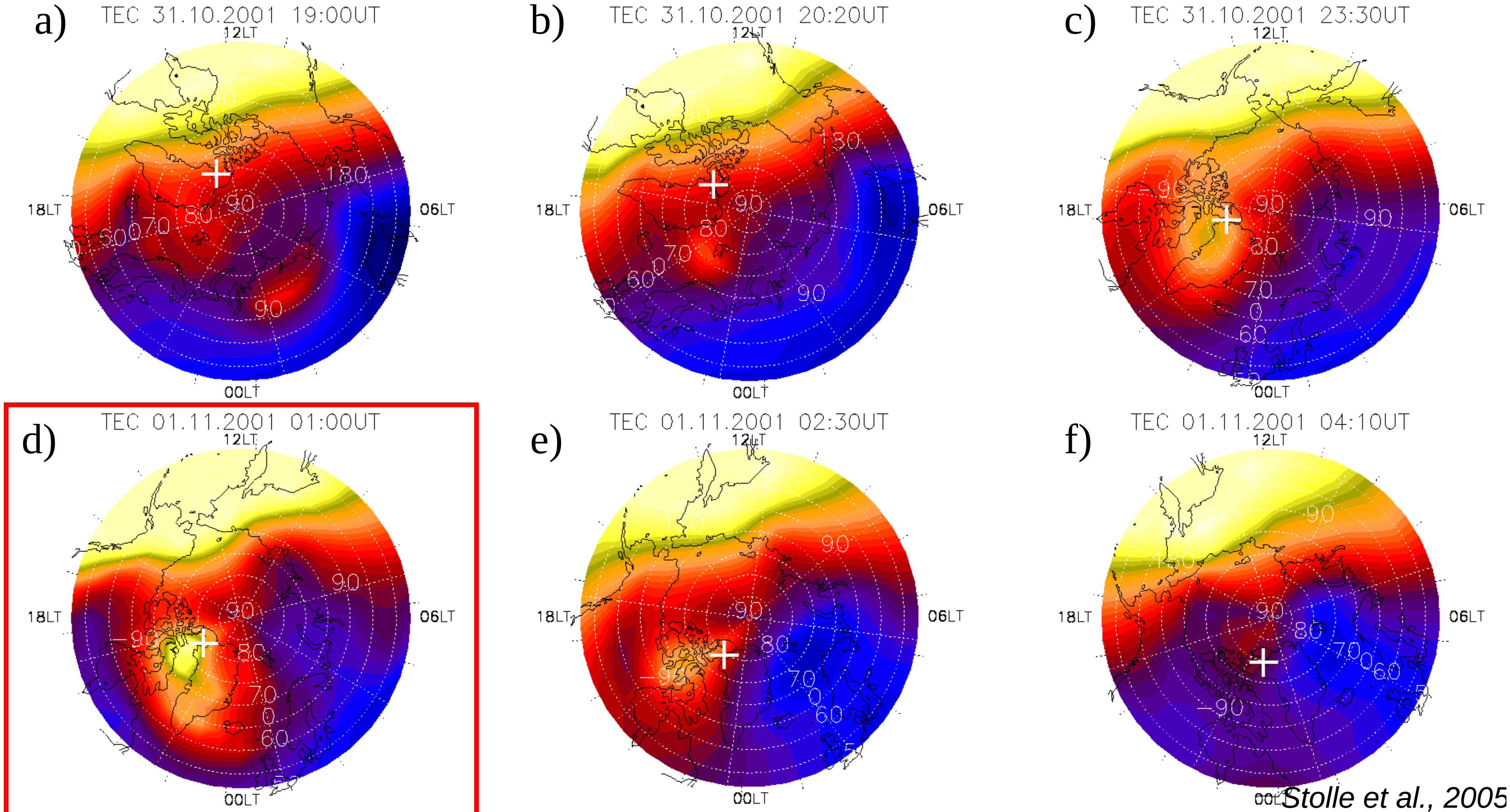
Stolle et al., 2005



Results (Example)



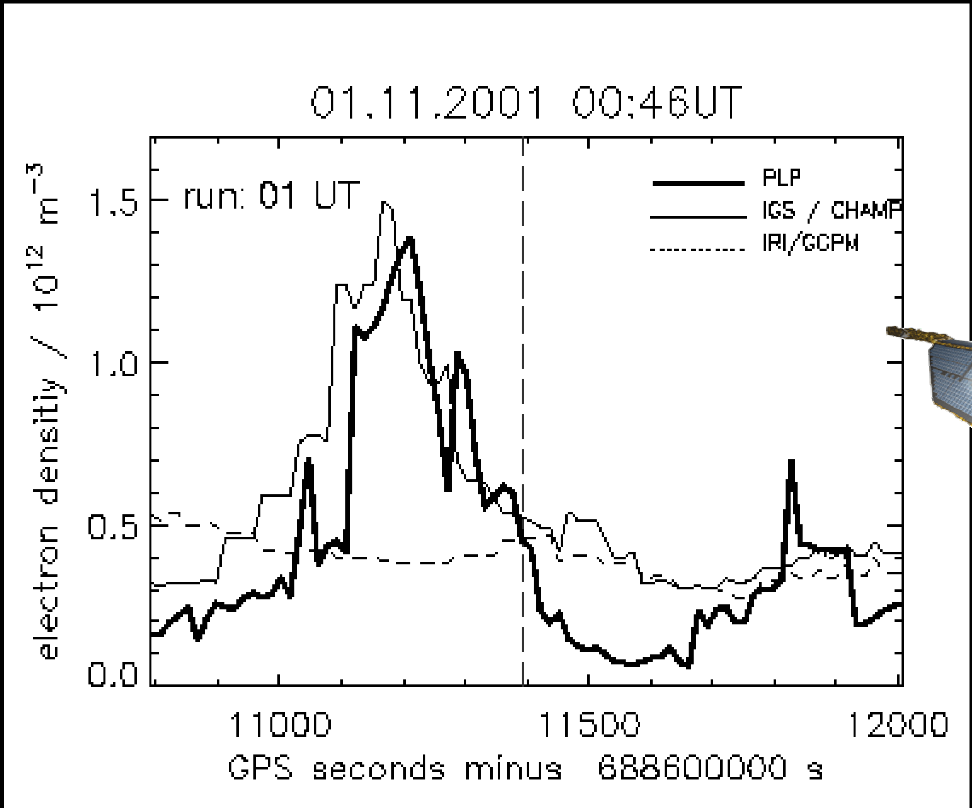
Night of Oct. 31 – Nov.1, 2001

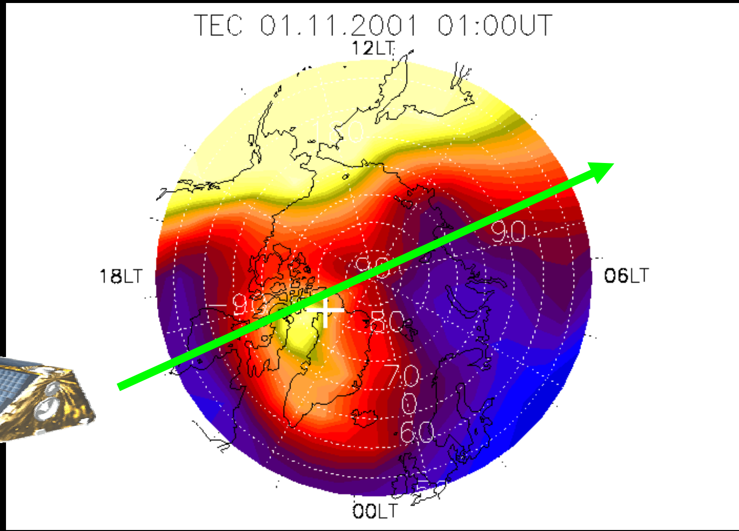


Stolle et al., 2005

Results and validation with PLP data

Night of Oct. 31 – Nov.1, 2001





PLP electron density along the CHAMP orbit at about 440km altitude

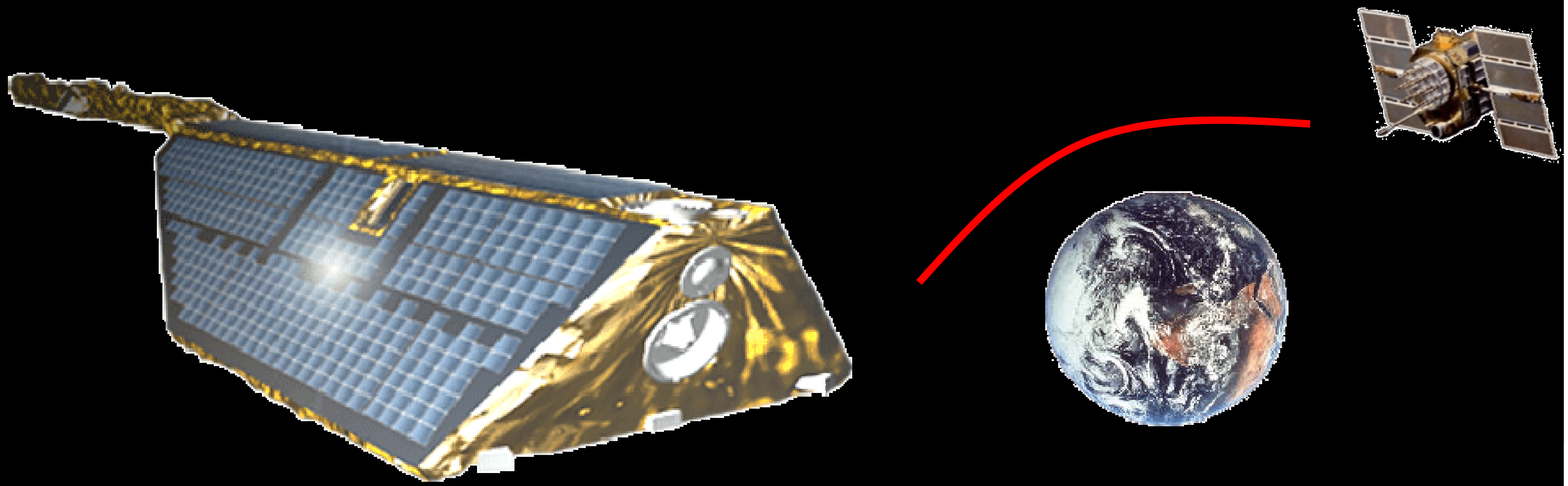
PLP

Assimilation

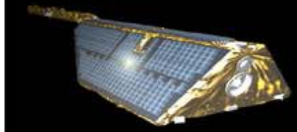
.... IRI/GCPM

Stolle et al., 2005

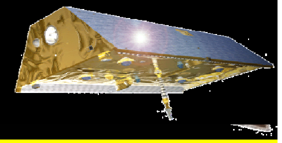
GFZ POTSDAM



Summary and Outlook

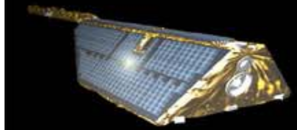


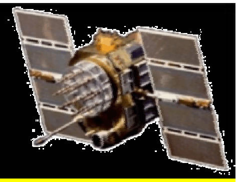
Summary & Outlook



- **First and unique long term set of GPS radio occultation data (currently ~200.000 vertical profiles) is expected to be extended until 2008)**
- **NRT occultation processing continuously demonstrated (average delay of ~4 hours reached)**
- **Several improvements of the occultation processing reached (e.g. single differencing, Lower troposphere data analysis, role of the GPS receiver, detection of reflections ...)**
- **Potential for various applications demonstrated (e.g. first successful impact studies for global NWP, First climatologies, reveal weaknesses of radiosondes and met. analyses, ionospheric studies ...)**
- **COSMIC will multiply the great potential, demonstrated by CHAMP!**

GFZ POTSDAM





Main conclusion: GPS radio occultation and GPS based remote sensing will have great future!