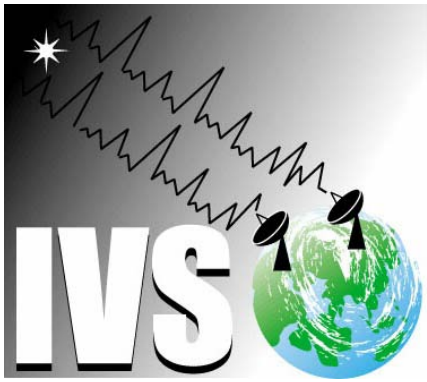
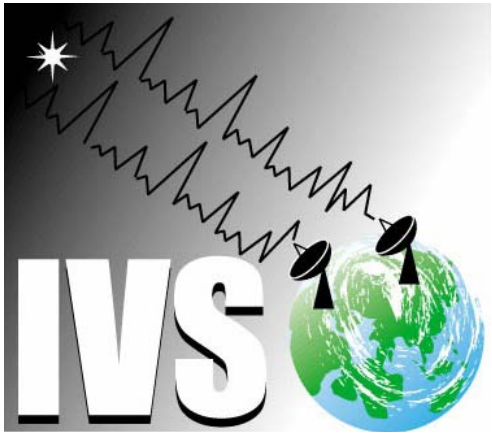


The IVS and its VLBI Global Observing System VGOS

Axel Nothnagel
Institute of Geodesy and Geoinformation, University of Bonn
and
many colleagues of the IVS

International VLBI Service for Geodesy and Astrometry



Contribution to IAG's
Global Geodetic Observing System (GGOS)

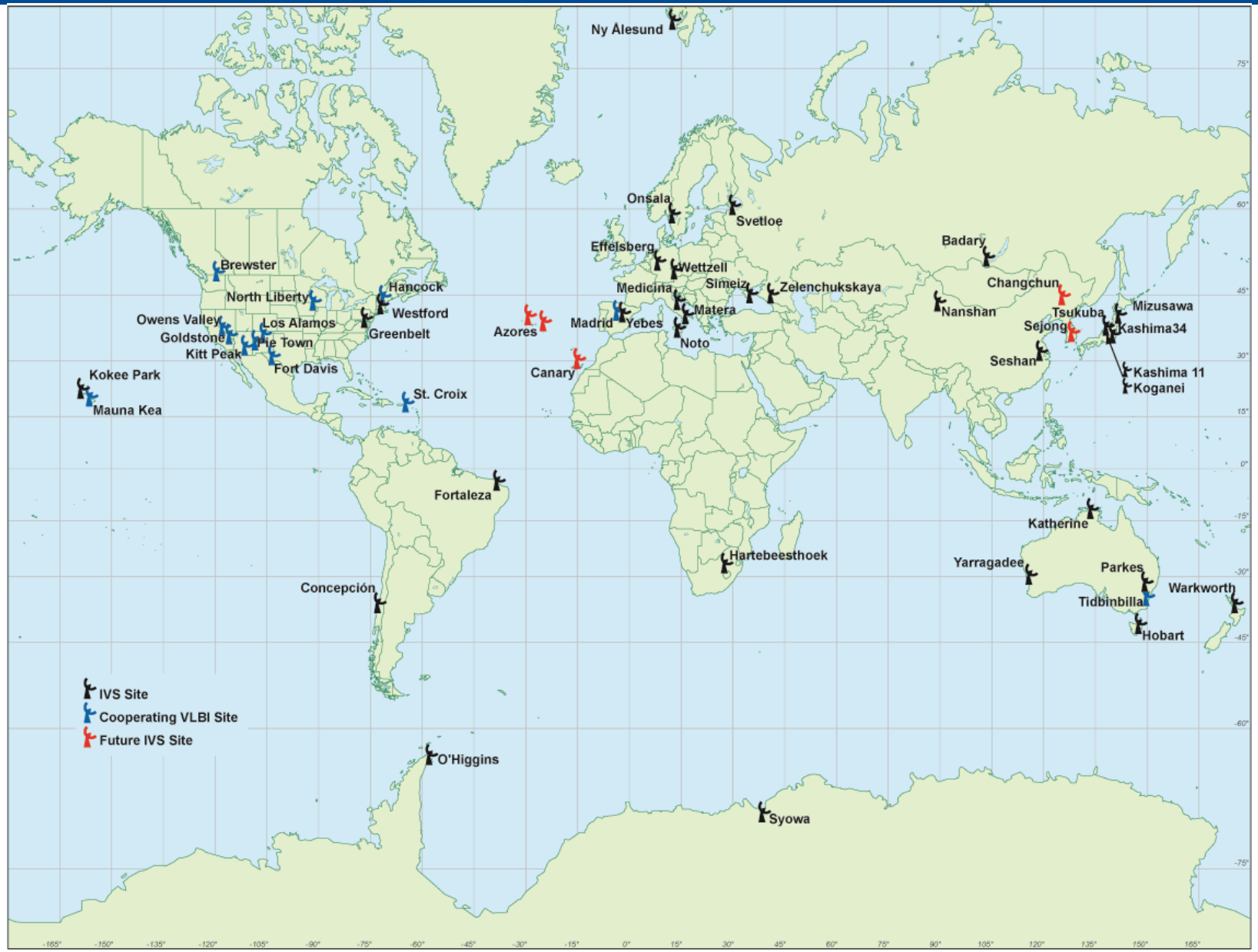
- 1 mm/0.1 mm/y
- continuous
- stable over decades
- global distribution

IAG 150 years International Association of Geodesy

Contents

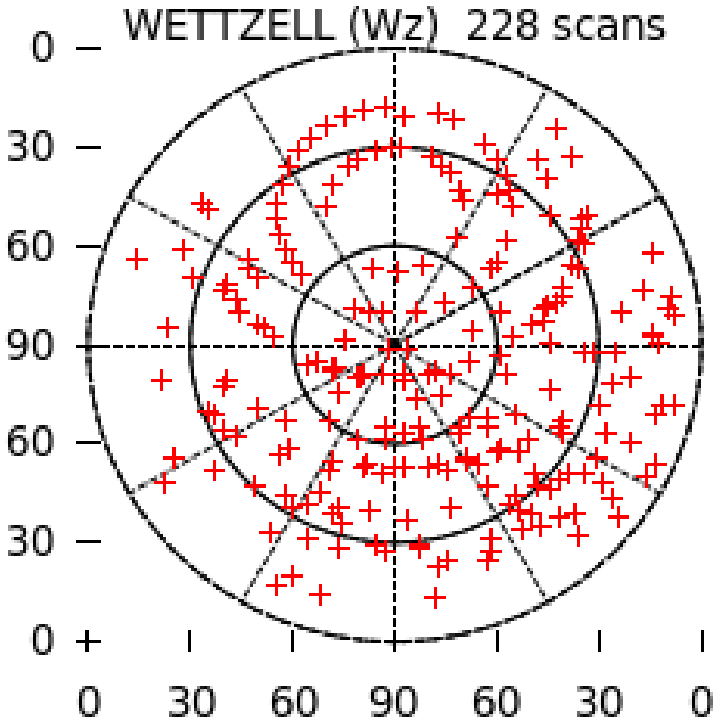
- Developments towards VGOS
  VLBI(2010) Global Observing System
  - Telescopes, Correlation, Analysis
  - Organisational aspects

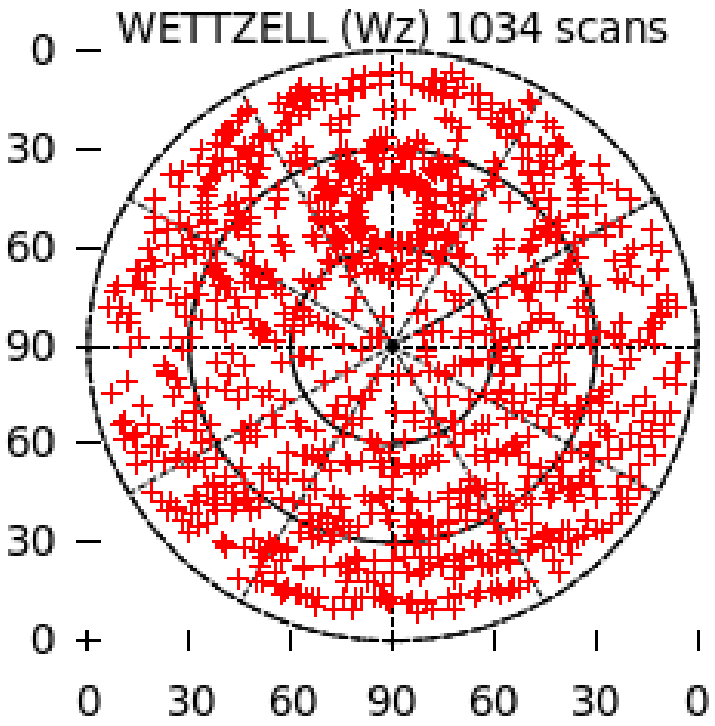
Current IVS Station Network



Concept of VLBI2010

- New generation VLBI infrastructure
  - dense sampling of local sky
    for optimal estimation of atmosphere parameters





Concept of VLBI2010

- New generation VLBI infrastructure
  - dense sampling of atmosphere
  - agile telescopes
    → small (12 – 13 m)
    12º/sec
  - up to 2 observations per minute (2880/day)

$$\sigma_\tau \propto \sqrt{\frac{1}{A_1 A_2 \cdot B}}$$

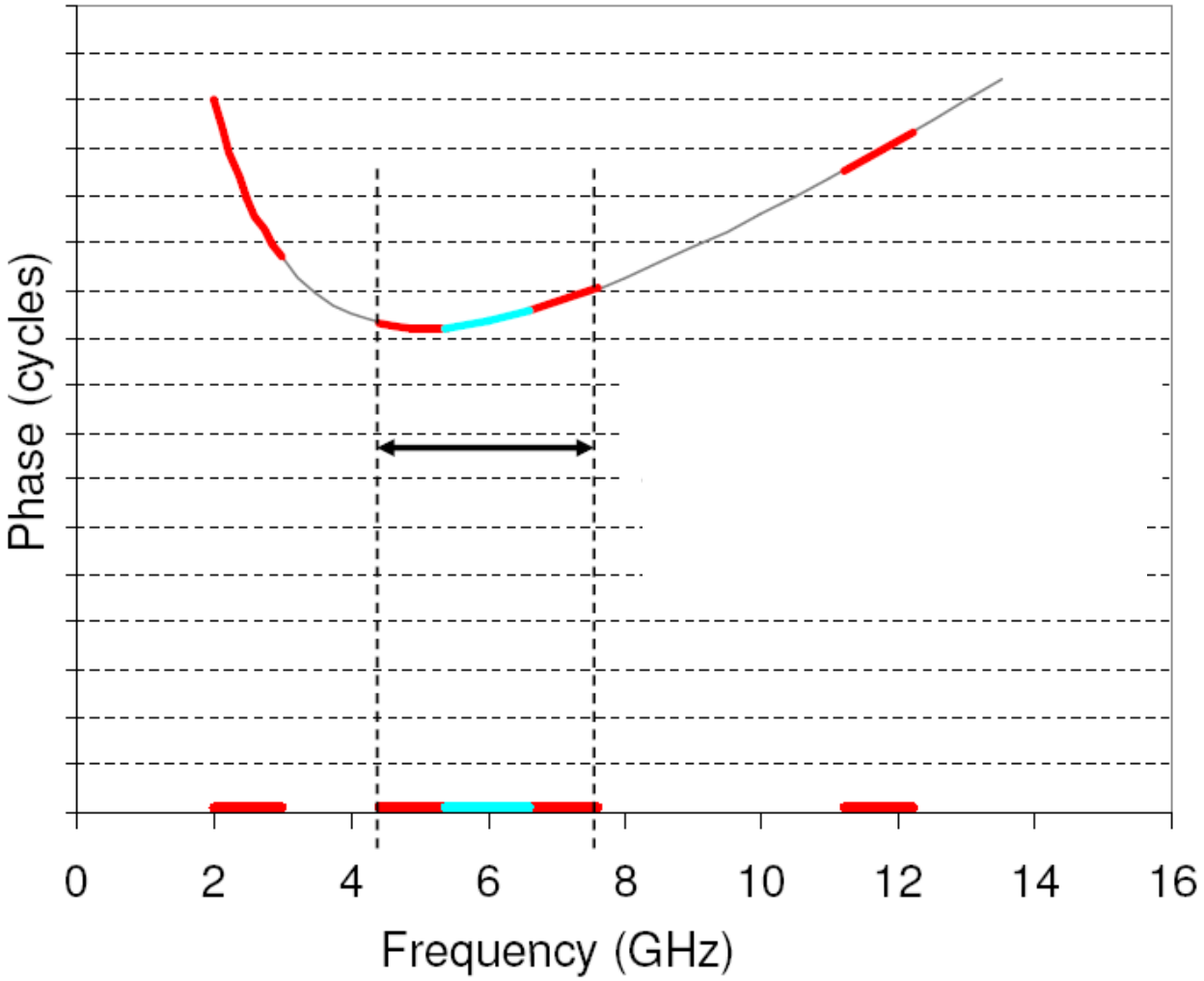
- Large bandwidth needed
  - wide band receivers (2 – 14 GHz)

VLBI Global Observing System

VLBI2010 Global Observing System
became
VLBI Global Observing System – VGOS

Small and agile telescopes
Large bandwidth (2 – 14 GHz)
Flexible frequency allocation
Dual linear polarization

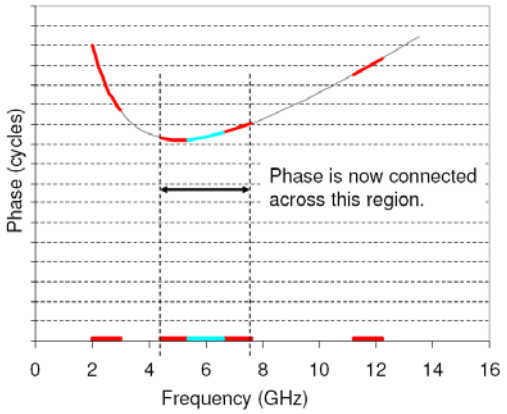
Frequency allocation for VGOS

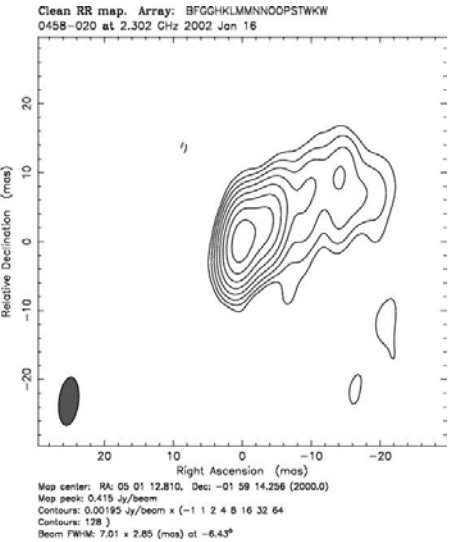


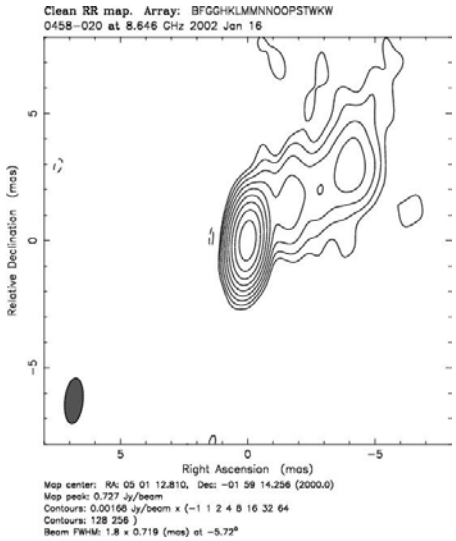
Courtesy B. Petrachenko

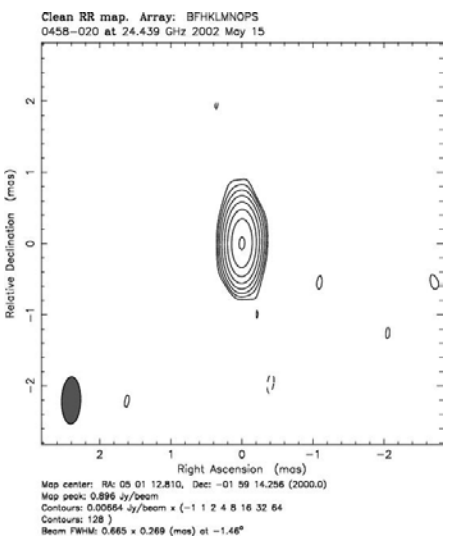
Challenges

- Frequency band selection
  - Radio frequency interference
  - Phase connection requirements
- Source structure effects









Images credit:
P. Charlot et al, AJ, 139, 5, 2010

S-band
2.3 GHz
13.6 cm

X-band
8.6 GHz
3.6 cm

K-band
24 GHz
1.2 cm

New VGOS radio telescopes

NyAlesund (NO)

Courtesy L. Langkaas

Zelenchukskaya (RU)

Courtesy
A. Ipatov

Ishioka (JP) Courtesy Y. Fukuzaki

GGAO (US)
Courtesy A. Niell

Badary (RU)

Courtesy
A. Ipatov

STATUS OF THE SPANISH/PORTUGUESE RAEGE PROJECT

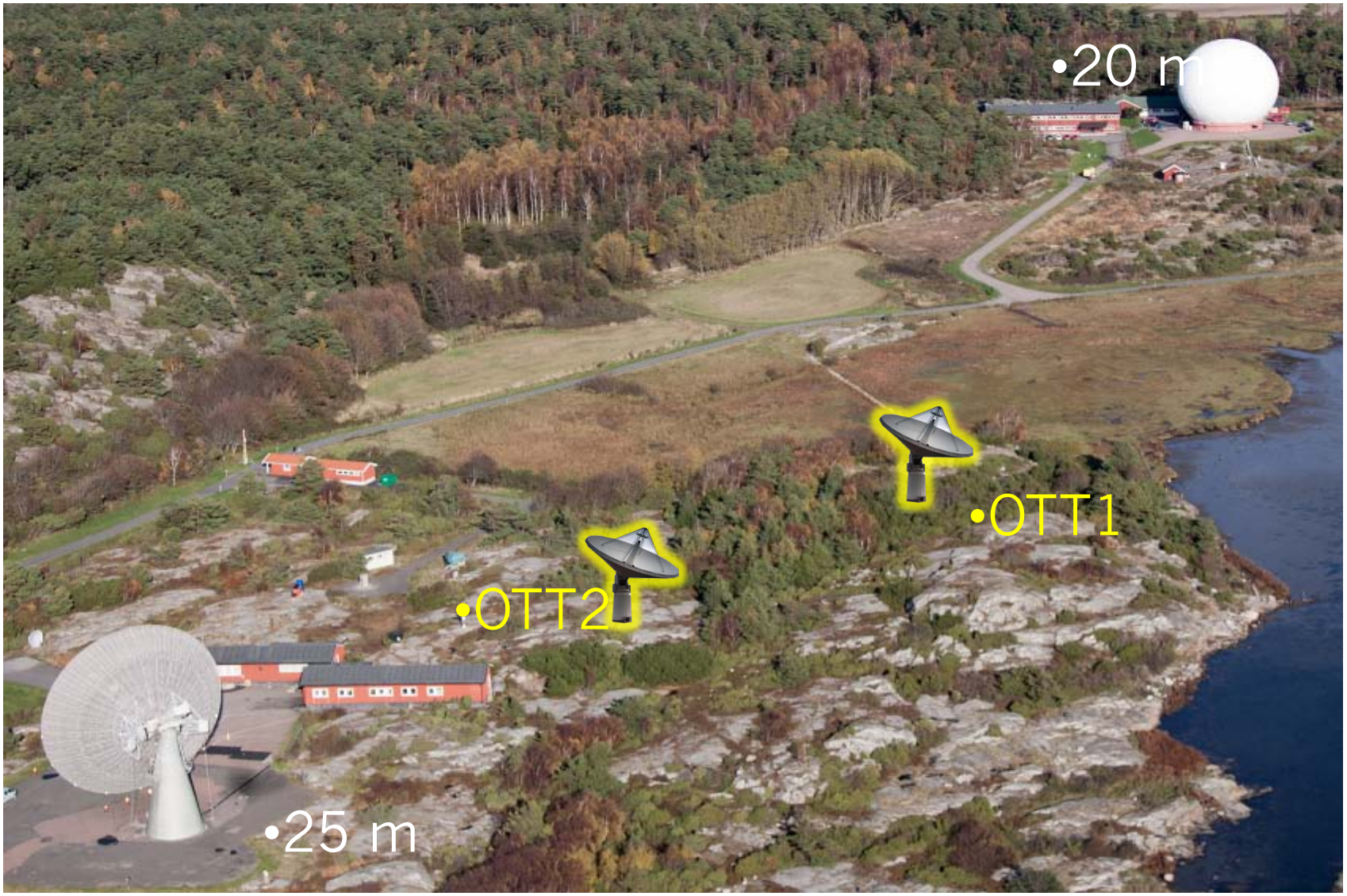
Gómez-González et al .(2013)

Yebes (Spain)
(August 2013) Courtesy: J.A. Lopez

Santa Maria (Eastern Azores)
(Sep. 2014) Courtesy: F. Colomer

Twin Telescope Wettzell

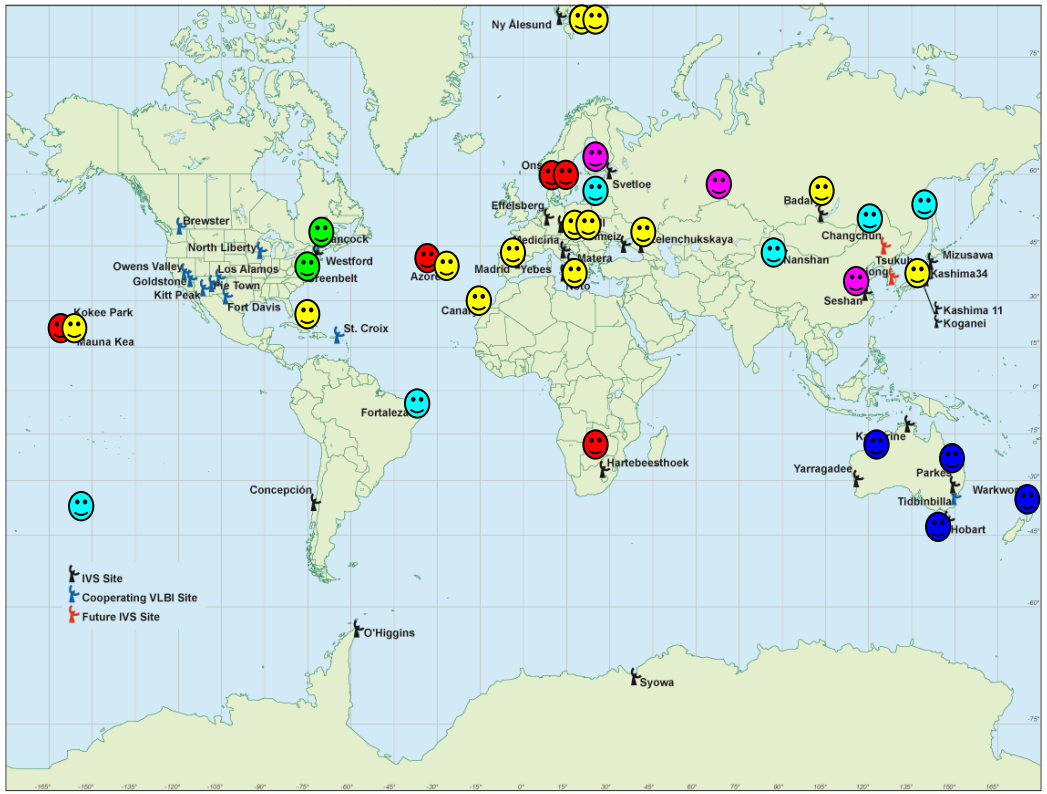
Twin Telescope Onsala



Courtesy R. Haas

VGOS World

New VGOS radio telescopes for IVS



- operational
- under construction
- funded
- proposal submitted
- planning phase
- planning phase upgrade

Courtesy H.Hase/VPEG,
based on available information
February 2014

VGOS Observing Plan (Pilot Project)

Monday	Tuesday	Wednesd.	Thursday	Friday	Saturday	Sunday
	R1		**R4**		**Broadband**	

VGOS Observing Plan (Densification Phase)

Monday	Tuesday	Wednesd.	Thursday	Friday	Saturday	Sunday
	R1		**R4**		**Broadband**	

VGOS Observing Plan (Densification Phase)

Monday	Tuesday	Wednesd.	Thursday	Friday	Saturday	Sunday
	R1		**R4**		**Broadband**	

VGOS Observing Plan (Densification Phase)

Monday	Tuesday	Wednesd.	Thursday	Friday	Saturday	Sunday
	R1		**R4**		**Broadband**	

VGOS Implementation Plan (Densification Phase)

Monday	Tuesday	Wednesd.	Thursday	Friday	Saturday	Sunday
	R1		**R4**		**Broadband**	

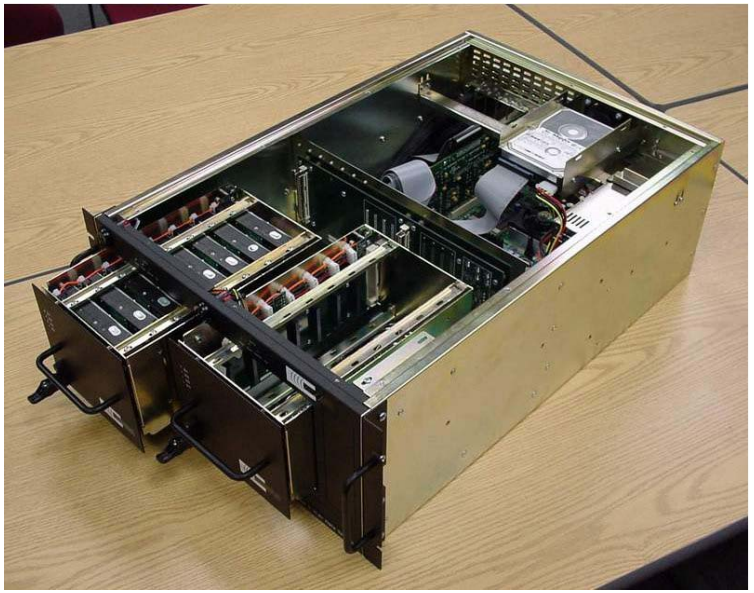
VGOS Observing Plan (Densification Phase)

Monday	Tuesday	Wednesd.	Thursday	Friday	Saturday	Sunday

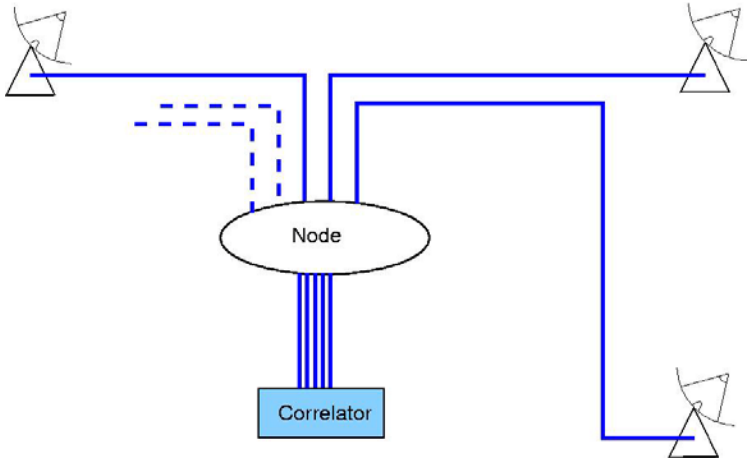
Data transport

Options

- Shipping disk modules
- Electronic transfer



Courtesy A. Whitney



Correlator connectivity

- MIT Haystack (US) 20 Gb/s
- GSI Tsukuba (JP) 10 Gb/s
- NEOS Washington DC (US), 1 Gb/s
- MPIfR/BKG Bonn (DE), 1 Gb/s

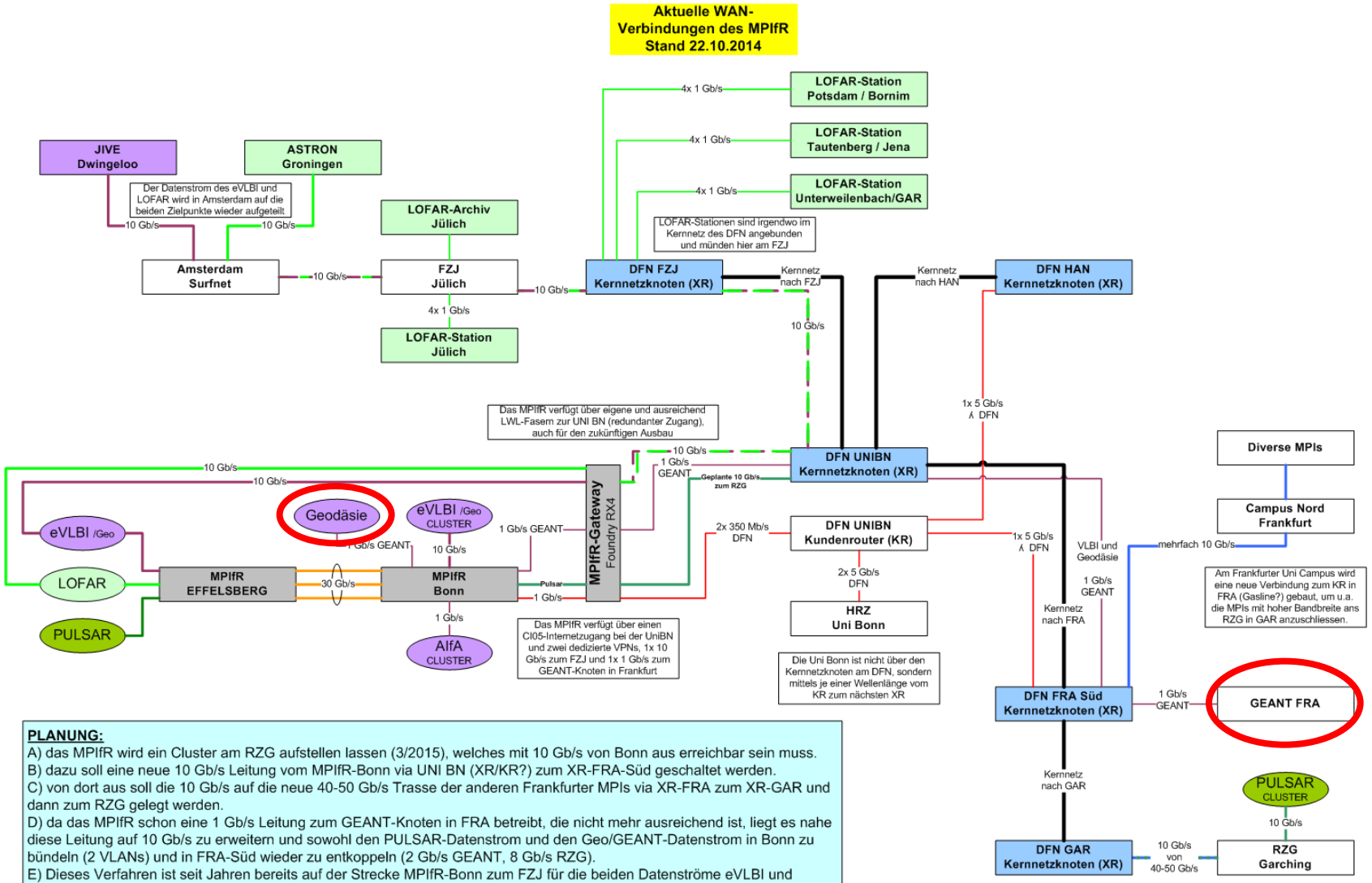
Data transport

Year	# of sites	hours of obs/day	data/day/site (TB)	data/day at correlator (TB)
2015	8	4	7.2	58
2016	10	8	14.4	144
2017	16	8	14.4	230
2018	20	10	18.0	360
2019	24	12	21.6	518
2020	24	24	43.2	1037

Year	data rate at each site (Gbps)	network data rate at each site (Gbps)	data rate at correlator (Gbps)	network data rate at correlator (Gbps)
2015	0.7	1.0	5	8
2016	1.3	1.9	13	19
2017	1.3	1.9	21	30
2018	1.7	2.4	34	48
2019	2.0	2.8	48	68
2020	4.0	5.6	96	134

VGOS Data Transmission and Correlation Plan 2014

Situation at Bonn



PLANUNG:

A) das MPIfR wird ein Cluster am RZG aufstellen lassen (3/2015), welches mit 10 Gb/s von Bonn aus erreichbar sein muss.
B) dazu soll eine neue 10 Gb/s Leitung vom MPIfR-Bonn via UNI BN (XR/KR?) zum XR-FRA-Süd geschaltet werden.
C) von dort aus soll die 10 Gb/s auf die neue 40-50 Gb/s Trasse der anderen Frankfurter MPIs via XR-FRA zum XR-GAR und dann zum RZG gelegt werden.
D) da das MPIfR schon eine 1 Gb/s Leitung zum GEANT-Knoten in FRA betreibt, die nicht mehr ausreichend ist, liegt es nahe diese Leitung auf 10 Gb/s zu erweitern und sowohl den PULSAR-Datenstrom und den Geo/GEANT-Datenstrom in Bonn zu bündeln (2 VLANs) und in FRA-Süd wieder zu entkoppeln (2 Gb/s GEANT, 8 Gb/s RZG).
E) Dieses Verfahren ist seit Jahren bereits auf der Strecke MPIfR-Bonn zum FZJ für die beiden Datenströme eVLBI und LOFAR im Einsatz. Die Entkopplung geschieht dabei tw. am FZJ oder spätestens in Amsterdam.

OFFEN:

1) Kosten der VPN-Leitung 10 Gb/s MPIfR-Bonn (bzw. XR-Uni Bonn) zum XR-Frau (Einsatz bald)
2) Kosten der Verbreiterung der Anbindung XR-FRA an GEANT-FRA auf mind. 2 Gb/s (Einsatz bald)
3) Kosten für eine Verbreiterung der Anbindung XR-UNI BN nach XR-FZJ auf 40 Gb/s für vorhandene 10 Gb/s ? (mittelfristig)

Correlation

Software Correlators

Estimated correlator cores required

Year	# of correlator cores
2015	200
2016	600
2017	900
2018	1400
2019	2000
2020	3900

Expected developments

Location	Correlator Cores		External Network (Gbps)	
	Now	Planned	Now	Future
Bonn	488	1000-1500	1	??
USNO	512	1024	1	10
Haystack	100	~300	20	no plan
Shanghai	64	1000	1	no plan
Tsukuba	92	256	10	no plan

PC cluster with off-the-shelve components (scalable)

Challenge: Power consumption (for processors and for cooling)

Data Analysis

Data analysis requirements in VGOS era

- Tremendeous increase in observables
- High degree of automatization required
- Different levels of latency
  - Near real-time
  - Rapid
  - Final
- Dependency on rapid availabilty of auxiliary data
  - Meteorlogical data
  - Mapping functions form numerical weather models

→ IVS Task force on seamless auxiliary data archives

Documentation

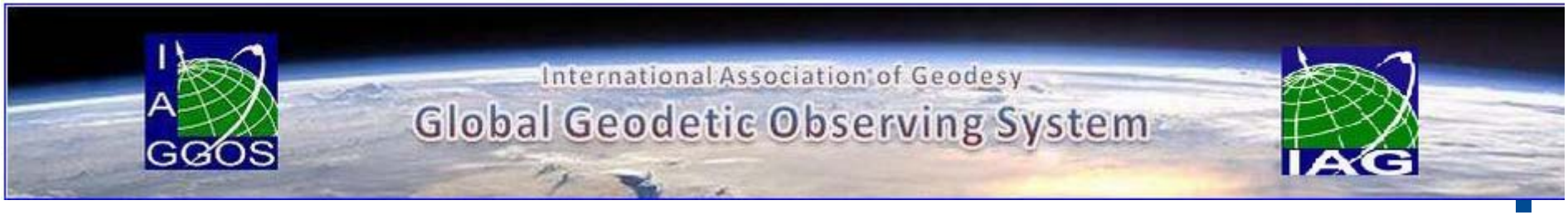
- VGOS Observing Plan
  Petrachenko W, Behrend D, Hase H, Ma C, Niell A, Nothnagel A, Zhang X (adopted by IVS DB)

- VGOS Data Transmission and Correlation Plan 2014
  Petrachenko W, Bertarini A, Alef W, Behrend D, Cappallo R, Hase H, Ma C, Niell AE, Nothnagel A, Zhang X (adopted by IVS DB)

- VGOS Analysis Plan
  Gipson J et al. (in preparation)

See
http://ivscc.gsfc.nasa.gov/technology/vlbi2010-documents.html

Global Geodetic Observing System

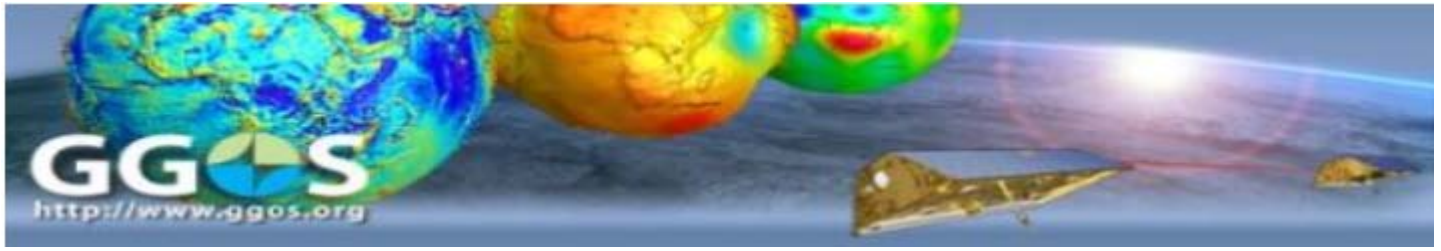


The mission of GGOS is:

- to provide the observations needed to monitor, map and understand changes in the Earth's shape, rotation and mass distribution;
- to provide the global frame of reference that is the fundamental backbone for measuring and consistently interpreting key global change processes and for many other scientific and societal applications;
- to benefit science and society by providing the foundation upon which advances in Earth and planetary system science and applications are built.

IAG 150 years International Association of Geodesy

Global Geodetic Observing System

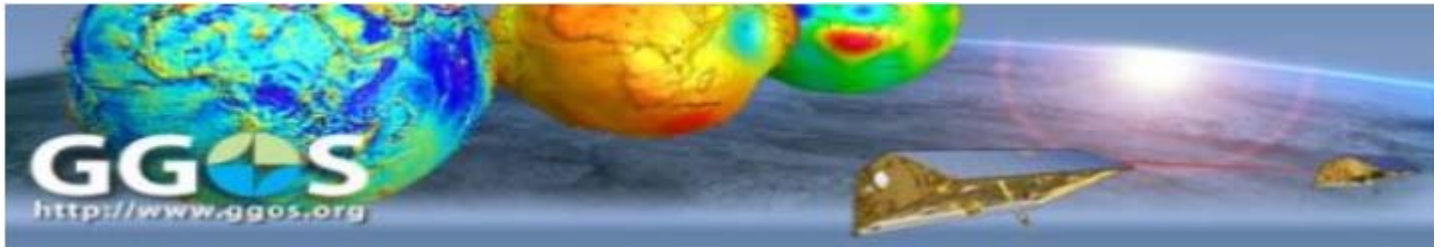


IVS → VGOS → GGOS

Requirements of GGOS

- Global distribution
- Continuous
- Stable over decades
- 1 mm/0.1 mm/y

Global Geodetic Observing System



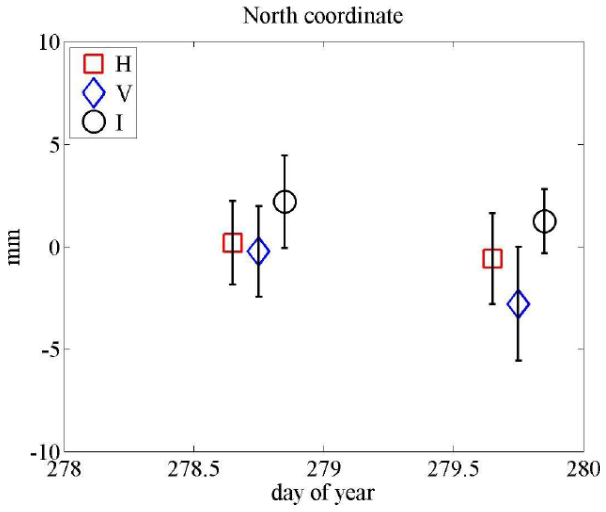
IVS → VGOS → GGOS

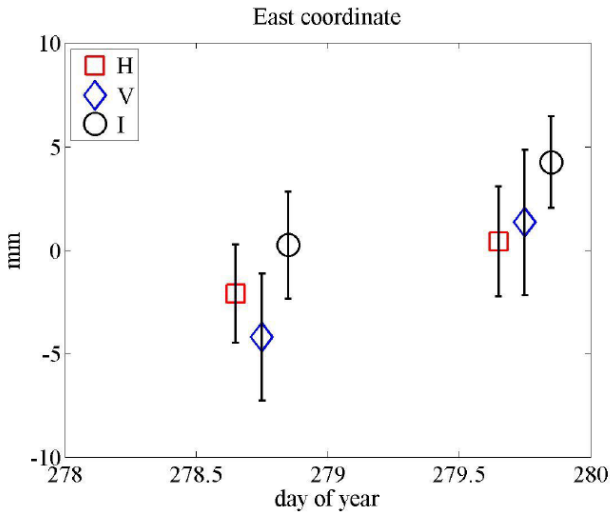
Contribution to GGOS

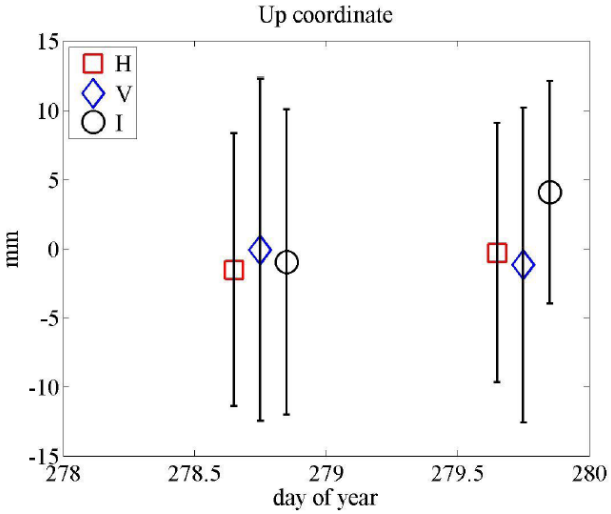
- Global distribution → Well-designed network
- Continuous → Economic operations
- Stable over decades → Monitoring of telescopes and local ties
- 1 mm/0.1 mm/y → Improved technology, better modeling

First broadband test results

Westford – GGAO baseline (600 km)
2x 6 hours, slightly different setups
8 Gbit/s with 32 standard disks (4 * Mark5C)







Niell et al. 2013

The future has started