International Association of Geodesy

GPSdancer

The **Geodetic Cloud Computing Service**: a new paradigm in GNSS analysis

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IGS workshop 2016
Sydney 8 -12 February

GCCS

cesah
Centrum für Satellitennavigation Hessen

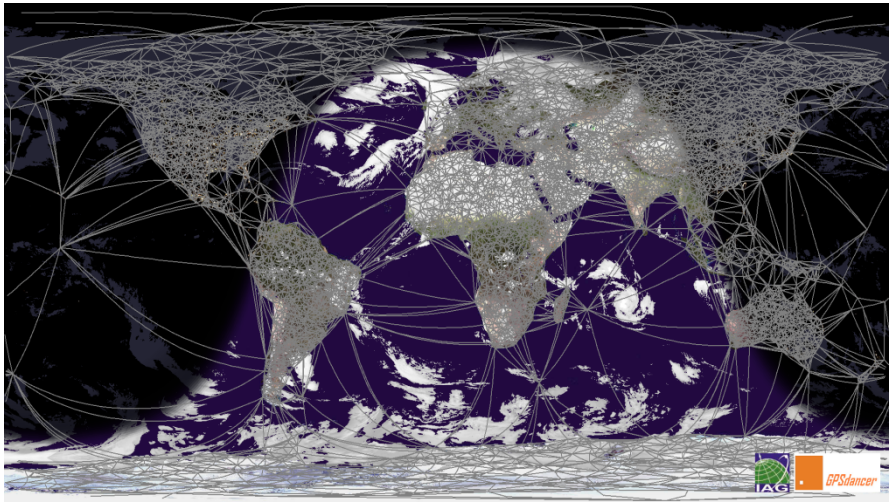
HESSEN

DARZ
Daten sind wertvoller als Geld

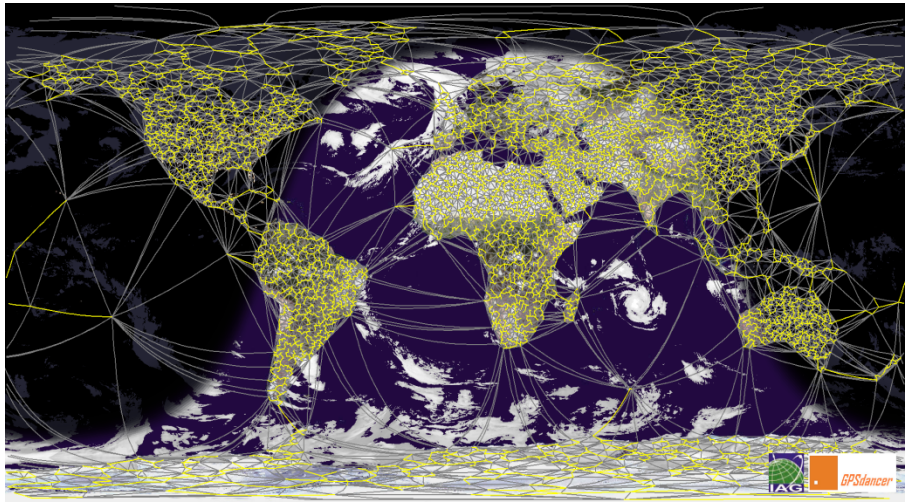
esa
business incubation centre
Darmstadt

GCCS output: ITRF network polyhedrons @ 30 min

orbits, satellite clocks, Earth rotation parameters are *by-products*



Delaunay triangulation N = 10,000

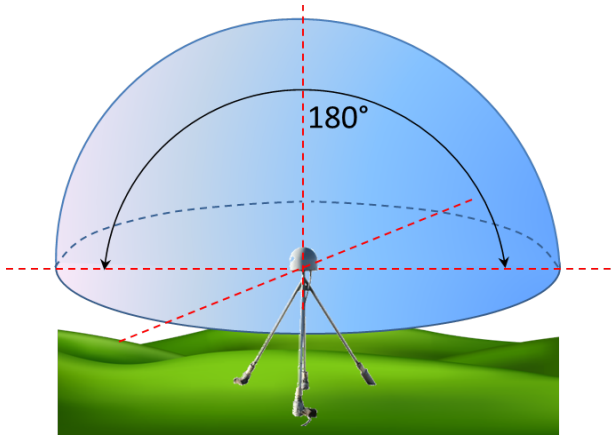


Ambiguities resolved along Minimum Spanning Tree

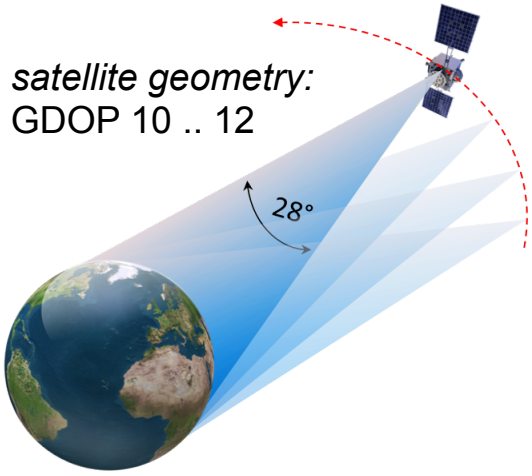
The GCCS is the operational service of the GPSdancer project

- Routine global network solutions based on GPSdancer instances in the cloud
- Target accuracy < 3 mm RMS w.r.t. formal ITRF for any static receiver
- Guaranteed consistency of models and standards (…IERS 2010, IGS repro 2)
- Operator privacy: input data & station products protected by RSA keys and NDA
- Paid service: participating network operators carry the cost of their own analysis
- *Under consideration*: guarantee of service covered by GCCS liability insurance

Global network analysis v. Precise Point Positioning



station geometry: GDOP 1 .. 2



satellite geometry:
GDOP 10 .. 12

~400 IGS stations

σ_{L1} 1 .. 2 mm → **global network solutions**

station geometry
σ_{sta} 2.8 mm
(IGS SINEX v. formal ITRF)

satellite geometry
σ_{sat} 20 mm
(IGS ACs v. combination)

"noisy" global satellite outputs become rigid PPP inputs

regional PPP solutions

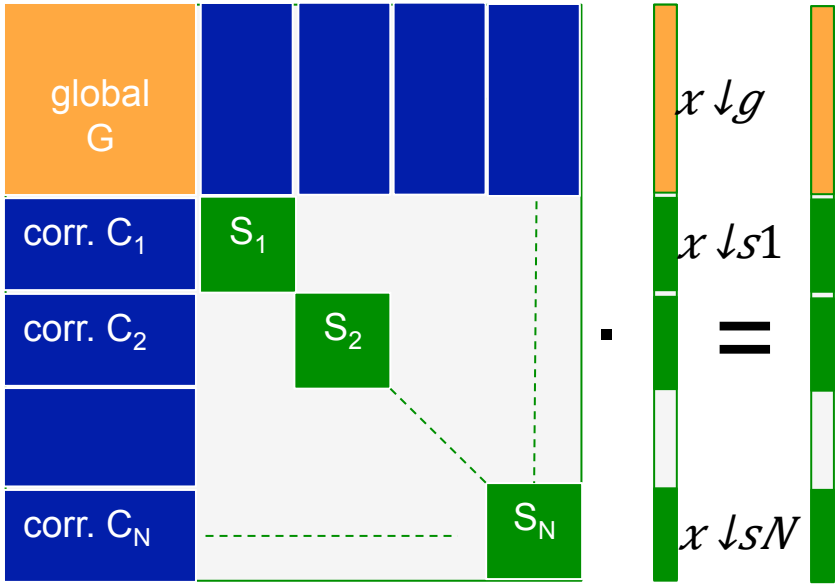
~30,000 regional CORS stations

station geometry
σ_{sta} 10 mm H, 20 mm V
(typical RTK networks, therefore: all end-users)

Why global solutions?

- Observability of global products is inferior to that of station products: avoid station dependency on abs. orbit accuracy
- Feedback between station products and the global ITRF network realization: *guaranteed analysis consistency*

GPS dancer / GCCS global batch least squares



← **Global parameters**: orbits, satellite clocks, Earth rotation parameters

← **Station parameters**: position, receiver clocks, troposphere, float ambiguities if relevant

Each **GPSdancer** instance *j* contributes:

$$\{ \blacksquare\blacksquare\ G\downarrow j\, x\downarrow g \ \&+\ C\downarrow j\, x\downarrow sj \ \&=\ y\downarrow gj\ \blacksquare C\downarrow j\uparrow t$$

GPS dancer initial design: (2 Mb/s)

- "Perfect constraint" solution method requiring square dance accumulation of *vectors*

GCCS operational approach: (1 Gb/s)

- *First* accumulate G on servers **per operator**
- *Then* accumulate G among all servers via a square dance accumulation of *matrices*

All station parameters can be pre-eliminated

$$\blacksquare x\downarrow sj = S\downarrow j\uparrow -1\ (y\downarrow sj - C\downarrow j\uparrow t\, x\downarrow g\ )$$

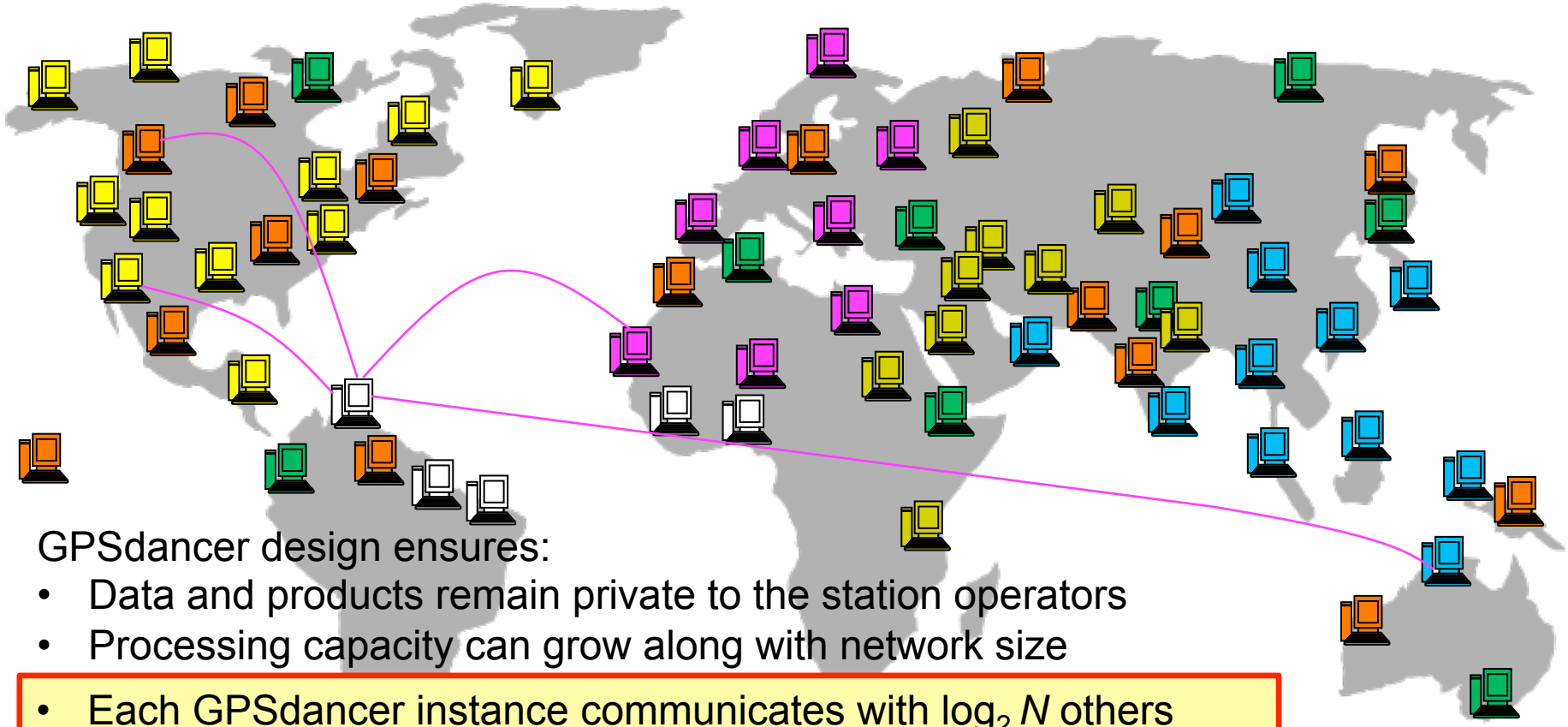
$$@\rightarrow\ (G\downarrow j - C\downarrow j\, S\downarrow j\uparrow -1\ C\downarrow j\uparrow t\ )x\downarrow g = (y\downarrow gj - C\downarrow j\, S\downarrow j\uparrow -1\ y\downarrow sj\ )$$

Global NEQ accumulated **on-line** to solve $x\downarrow g$

$$\blacksquare\ @\ \sum j\uparrow\ (G\downarrow j - C\downarrow j\, S\downarrow j\uparrow -1\ C\downarrow j$$

Initial GPSdancer design: public P2P process

one process per receiver, on **public** internet (~2 Mb/s design speed)



GPSdancer design ensures:

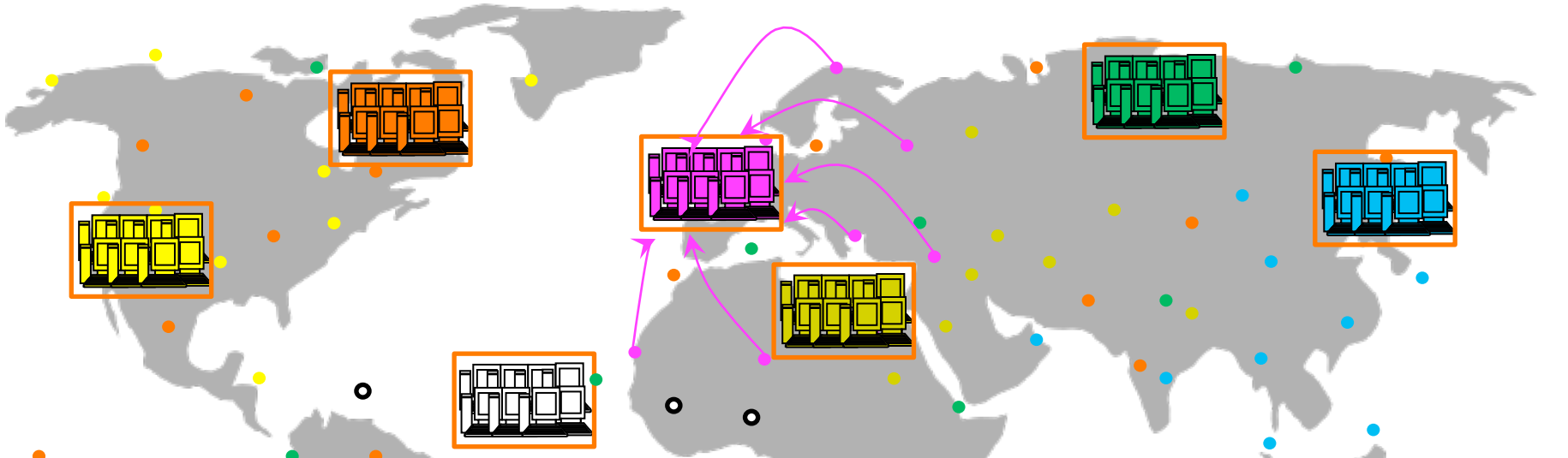
- Data and products remain private to the station operators
- Processing capacity can grow along with network size

- Each GPSdancer instance communicates with $\log_2 N$ others
- Connections may change whenever the network changes

No practical solution was found (so far) for maintaining all firewalls!

GCCS operational layout: clustering of GPSdancer instances

still one process per receiver, but **private** cloud servers per operator

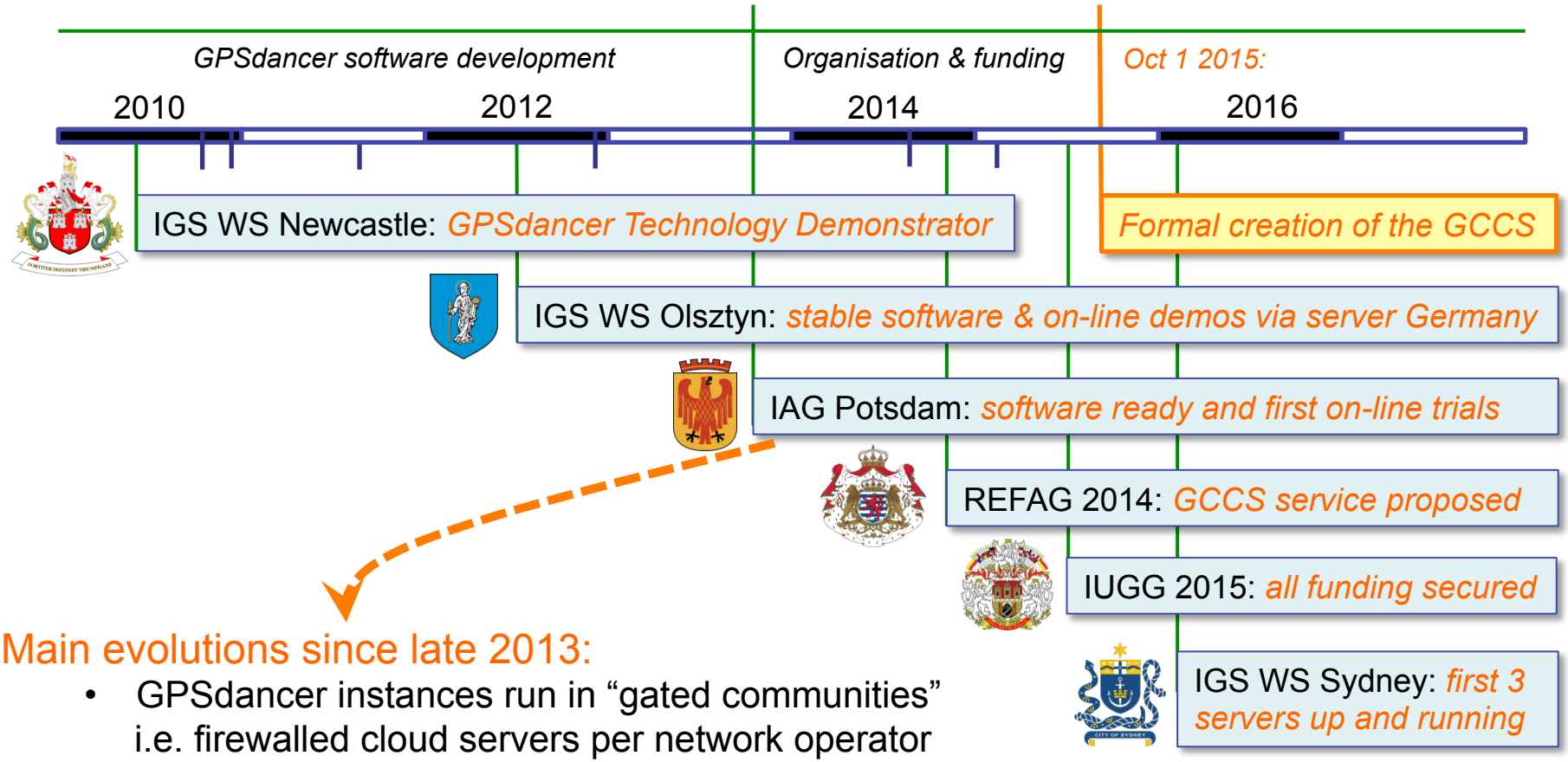


- Internet security issues solved by double firewall logic
- Signicantly faster communication links (> 1 Gb/s) in cloud

Each server has two IP addresses with separate firewall rules

- Operator has a private IP for input data & output products
- GCCS has second IP for communication between servers

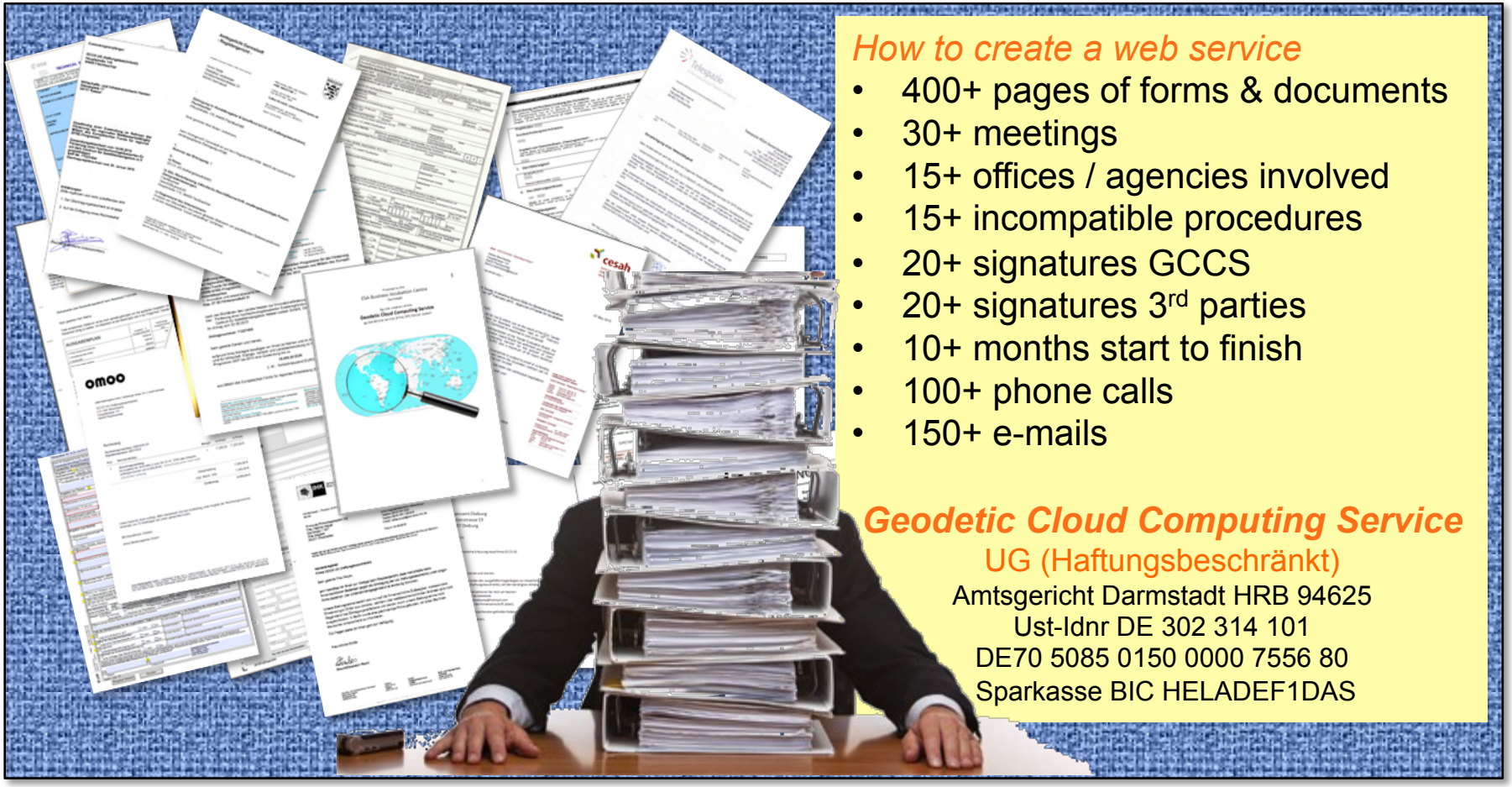
Timeline GPSdancer project and GCCS creation



Main evolutions since late 2013:

- GPSdancer instances run in “gated communities”
  i.e. firewalled cloud servers per network operator
- Cost reduction: GCCS no longer needs investors from industry
  start-up funding is now 50% **ESA** (BIC DA) and 50% **EU** (Hessen/EFRE)

1st Oct 2015: formal creation of the GCCS



How to create a web service

- 400+ pages of forms & documents
- 30+ meetings
- 15+ offices / agencies involved
- 15+ incompatible procedures
- 20+ signatures GCCS
- 20+ signatures 3rd parties
- 10+ months start to finish
- 100+ phone calls
- 150+ e-mails

Geodetic Cloud Computing Service

UG (Haftungsbeschränkt)

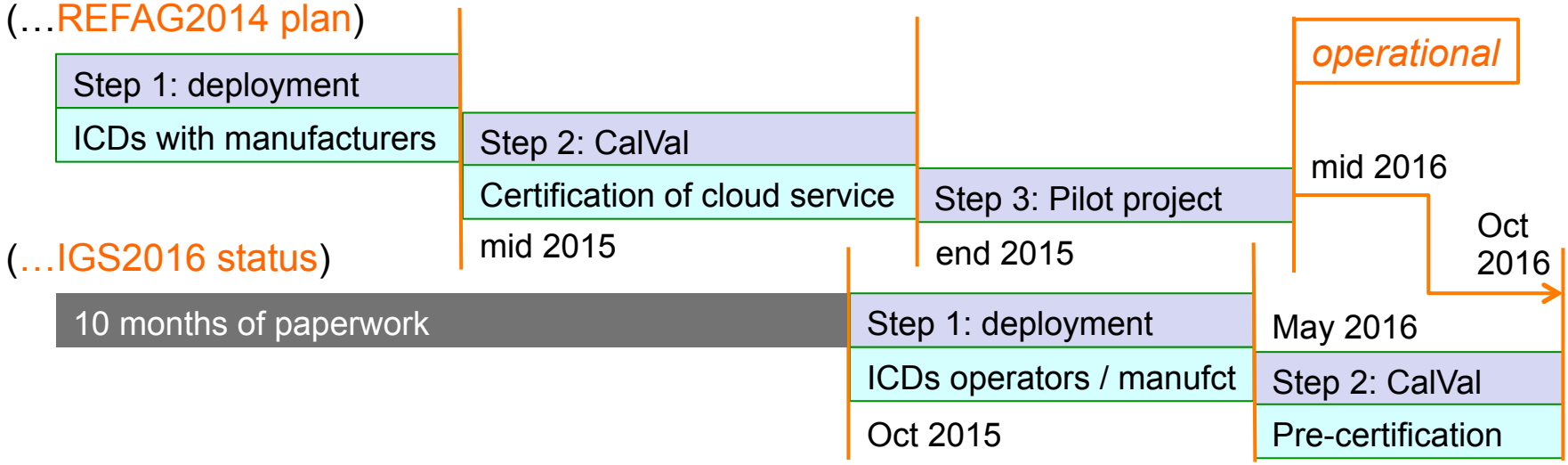
Amtsgericht Darmstadt HRB 94625

Ust-Idnr DE 302 314 101

DE70 5085 0150 0000 7556 80

Sparkasse BIC HELADEF1DAS

Status and schedule

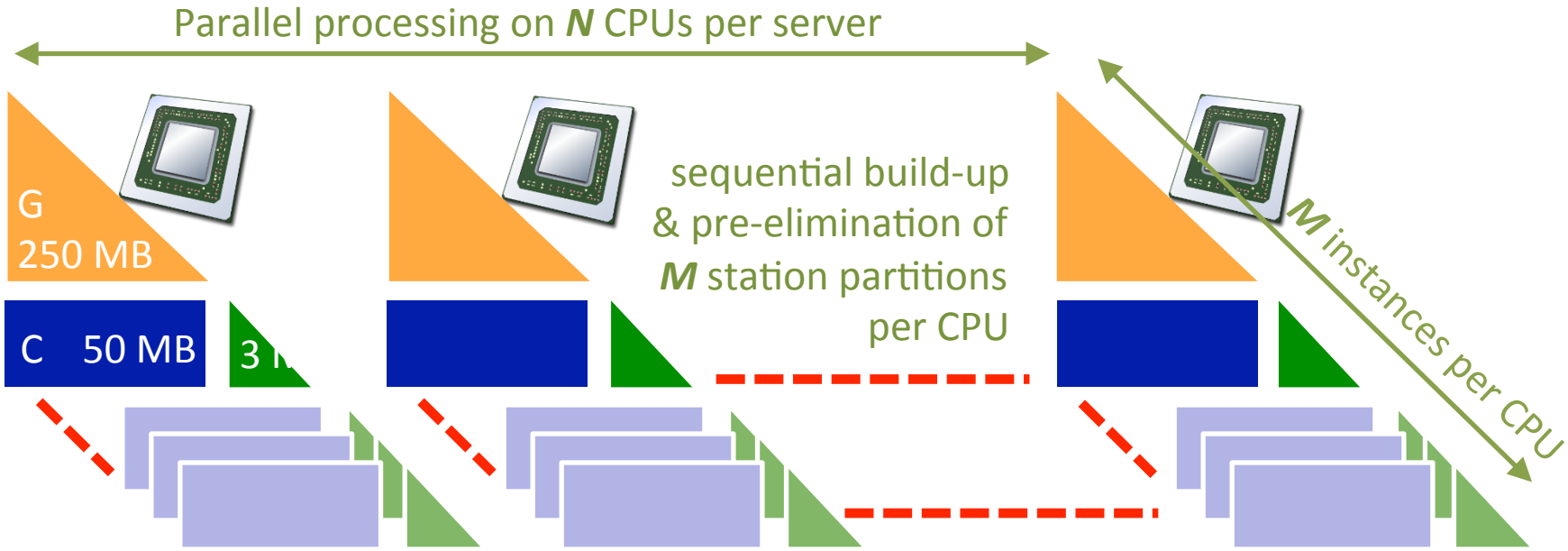


- Deployment: Oct 2015:

  3x **server @ 8 CPU & 32 GB RAM** until 10/2018
  1x **server @ 2 CPU & 8 GB RAM** indefinitely
  1x **virtual server @ 1 CPU** indefinitely
  + incidental test capacity @ DARZ Darmstadt

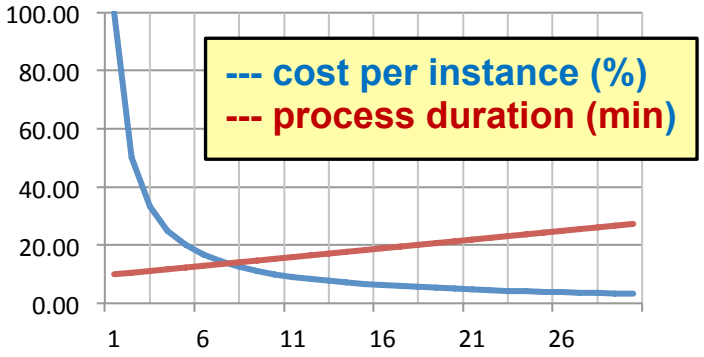
- CalVal to be reduced from 6 months to < 4 months
- Pilot project to be replaced by 3-month free trials for any network operator

NEQ accumulation (1): internal accumulation per server

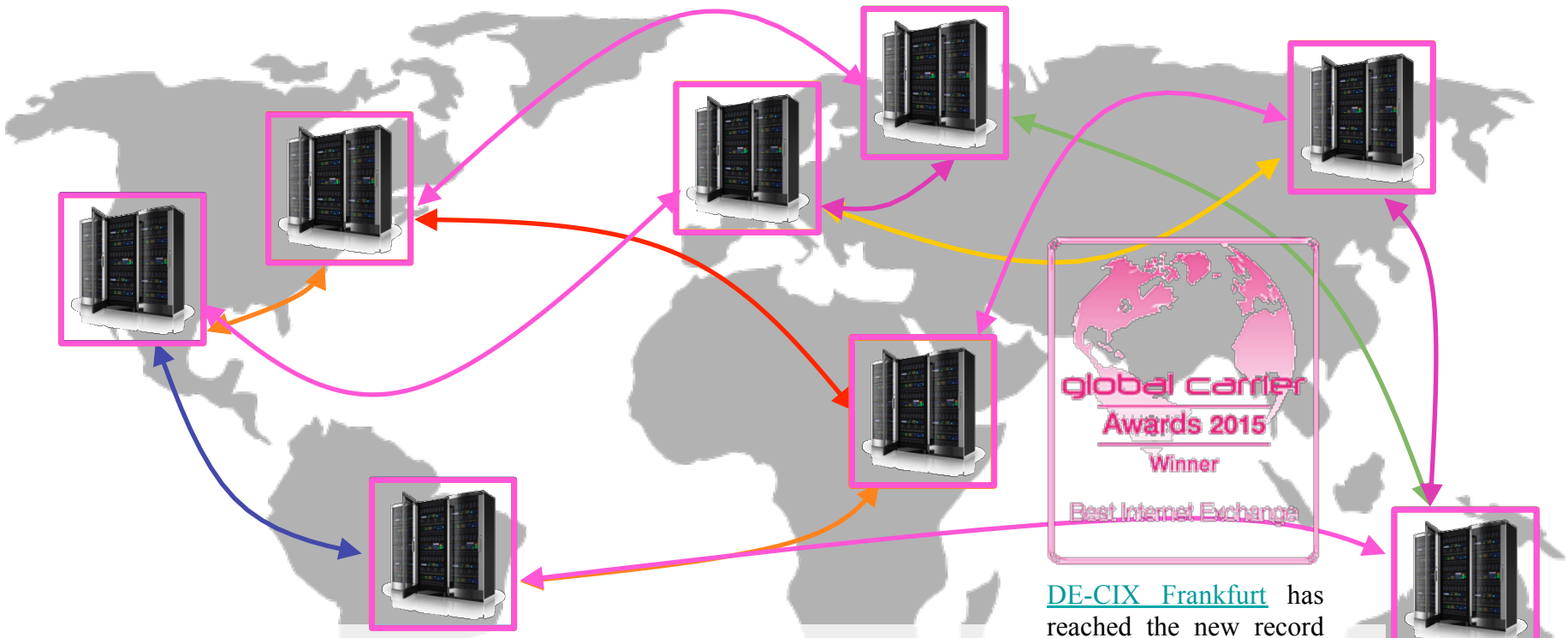


Sequential matrix accumulation of ***M*** instances per CPU:

- Amount of RAM per CPU is now independent of ***M***
- Cloud computing **cost** per instance decrease by ***1 / M***
- Product **latency** increases as ***L = A + B.M***
- GCCS baseline: ***M = 25, L = 30 minutes***



NEQ accumulation (2): square dance process among servers



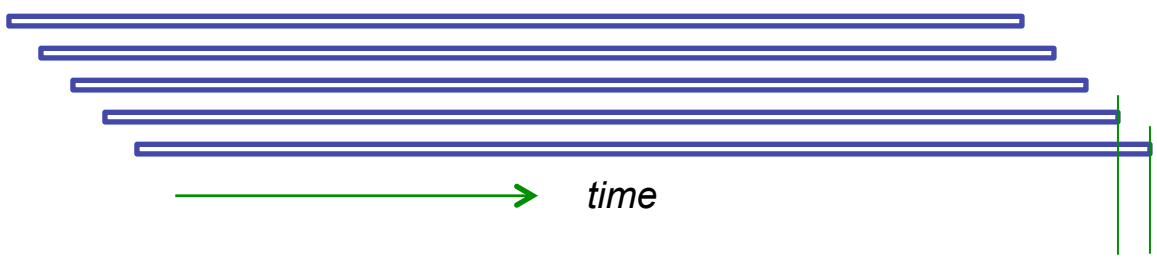
DE-CIX Frankfurt has reached the new record of **5 terabits per second in December 2015**

"Square-dance" accumulation algorithm between ***n*** servers

- Number of sequential exchange cycles is $\log_2 n$
- GCCS home: **DARZ** (www.da-rz.de) + AWS Frankfurt
- GCCS servers must have 1Gb/s to *Frankfurt Ring*

n =100: 7 cycles x 250 MB x 8 bits = 14 Gb <= 14 seconds

GCCS routine analysis @ 30 min intervals



- Conventional batch LSQ
- 24 hr arc length
- 30 sec output clocks

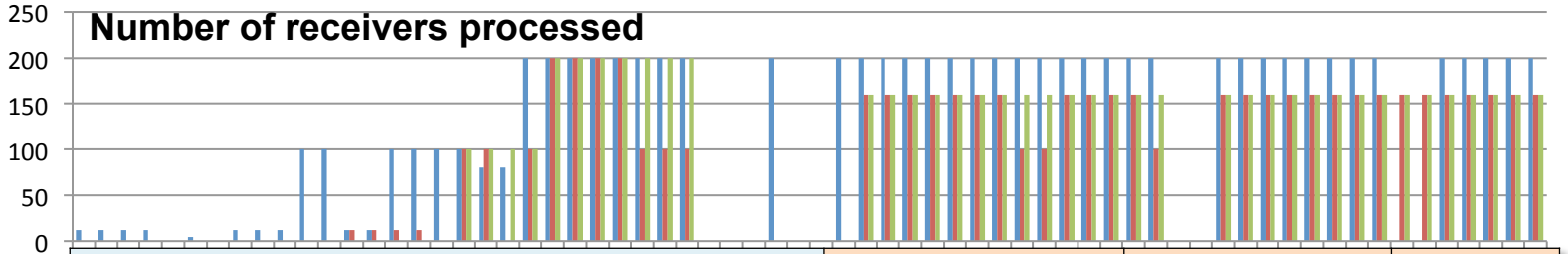
← *only 30 min of new data per arc*

station positions & troposphere

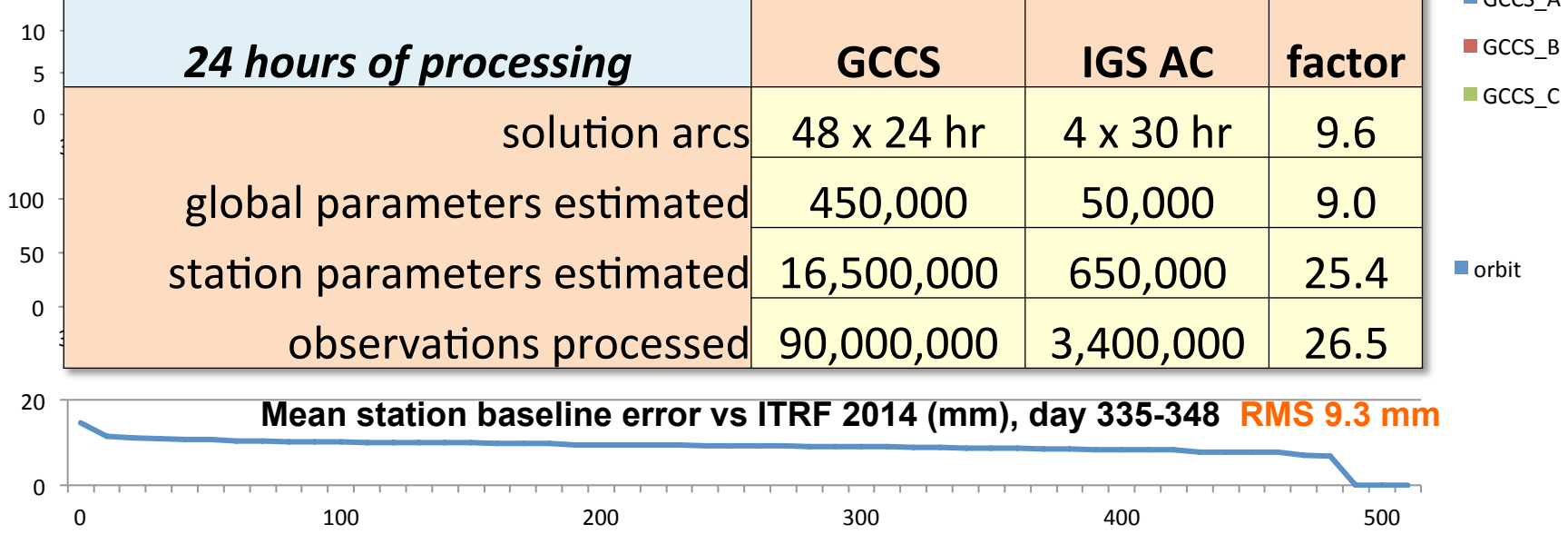
Data cleaning & initialization → LSQ fit "float solution" (zero diff.) → EMST ambig resolution (double diff.) → LSQ fit "precise run" (double diff.) → LSQ fit (zero diff.) → clocks

Purpose:	Initialization new data	Arc decoupling	*Ambiguity resolution based on AmbiZap (Blewitt & al.) but adapted to parallel processing, and to single diff. exchange along true EMST baselines.*	Accurate geometry	Clocks
Orbits	Fit to a priori	Estimated		Estimated	Fixed
Sat clocks	New data only	Estimated		n/a	Estimated
ERP	Fixed	Estimated		Estimated	Fixed
Sta pos	Fixed	Estimated		Estimated	Fixed
Sta clocks	New data only	Estimated		n/a	Estimated
Troposphere	Fixed	Estimated		Estimated	Fixed
Ambiguities	Fixed	Estimated		Unresolved amb. estimated	Estimated
Phase L3	20 mm	7 mm		2 mm	7 mm
Code P3	90 cm	80 cm		80 cm	80 cm

The first GCCS solutions: Nov/Dec 2015



24 hours of processing	GCCS	IGS AC	factor
solution arcs	48 x 24 hr	4 x 30 hr	9.6
global parameters estimated	450,000	50,000	9.0
station parameters estimated	16,500,000	650,000	25.4
observations processed	90,000,000	3,400,000	26.5



Cost breakdown

GCCS is a *paid service*: network operators must carry the cost for what they use

GCCS	• For every 1000 stations, GCCS can fund1 full time job or equiv.
Liability insurance	• *Optional*: collective insurance offers GCCS Guarantee of Service
ITRF backbone	• *Should phase out* if IGS operators are willing to pay their own cost

Cloud computing	• *Variable* - depends on operator requirements, e.g.:
	  • Redundant processing (geographically separated servers)
	  • Physical security level
	  • Optional cloud archiving of data and/or products

~$500/yr

Current GCCS server capacity is available until at least October 2018

- 650 stations = **400 IGS** + **250 free trials,** **25 stations @ 3 months per operator**

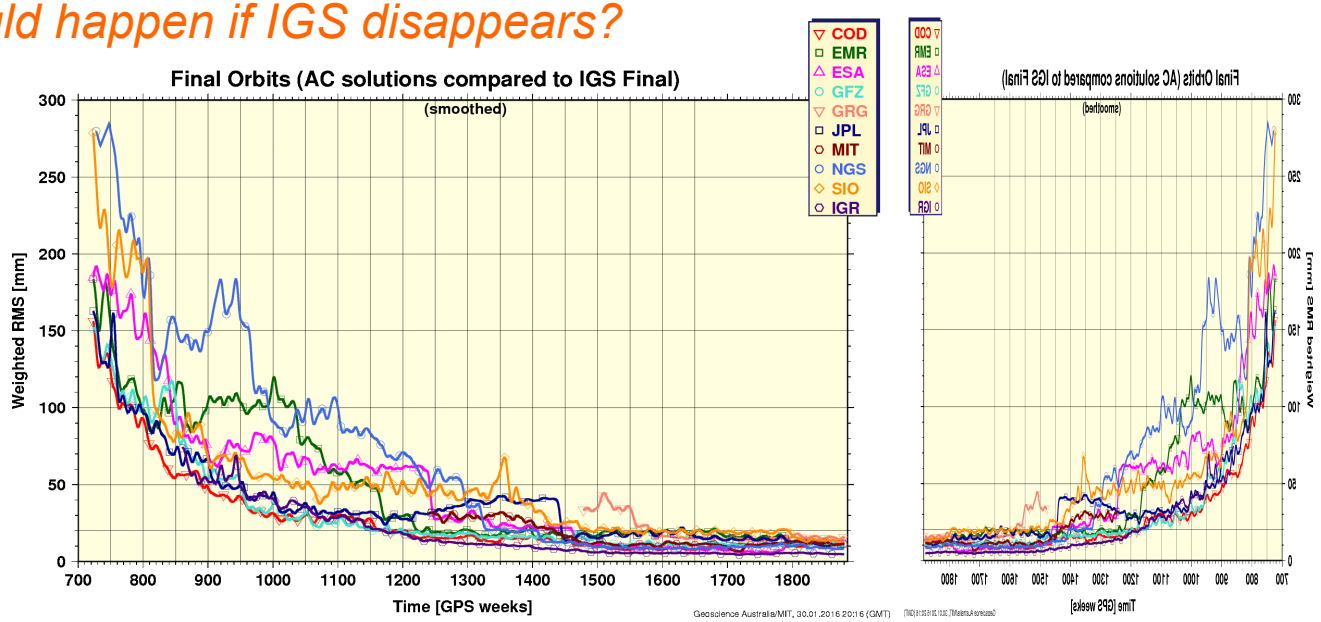
… first come, first served – requests to info@ITRF.online

Do we still need the IGS/ITRF?

…yes! The GCCS merely compLetes the IGS

- The **IGS** *defines* an accurate reference frame for just a few hundred points on Earth
- The **GCCS** *transfers* the ITRF to all regional stations (,..and therefore to end-users)

What would happen if IGS disappears?



- The **IGS** tends to emphasize its *products*, but probably more important are:
  - Continuous feedback among state-of-art GNSS analysis from all agencies
  - International cooperation among many participating organisations

Summary

- GCCS places all stations in global analysis along with the ITRF stations
  - *as opposed to*: feeding regional stations with orbits and clocks as ITRF reference
  - All stations get direct baselines to the ITRF stations, i.e. ITRF position time series
  - IGS ACs routinely demonstrate that accuracy of this analysis ***can*** be 2.8 mm RMS
- GCCS cloud deployment (…3 large servers) started Oct 2015
  - Generous computing capacity secured until at least Oct 2018
- Formal CalVal campaign against IGS expected from May to Sep 2016
  - Publication of CalVal report marks the formal start of GCCS operations
- Free trials will be available for all interested network operators
  - 64 trial slots, up to 3 months of GCCS analysis for 25 sites (economic value ~$3000)
  - Questions & requests for trial slots: **info@itrf.online**

Next IGS workshop: routine ITRF realizations for 10,000+ sites?