Precise Positioning Infrastructure in the Service of Science & Society

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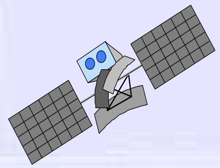

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Vice President International Association of Geodesy (IAG);

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Chair of the AuScope Geospatial Steering Committee;

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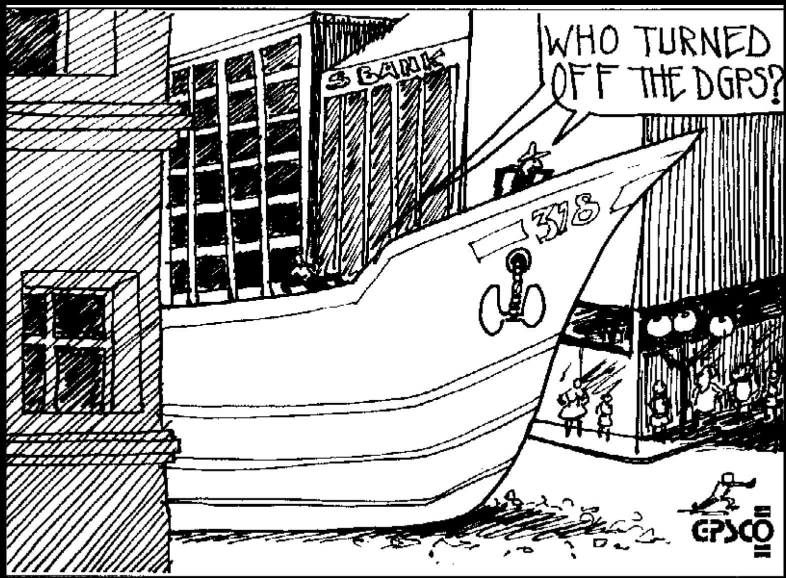
GNSS constellations must be AUGMENTED to address their shortcomings in <u>Availability</u>, <u>Integrity</u> and <u>Accuracy</u>…

Differential GPS (DGPS) is one of the earliest forms of augmentation…



Infrastructure

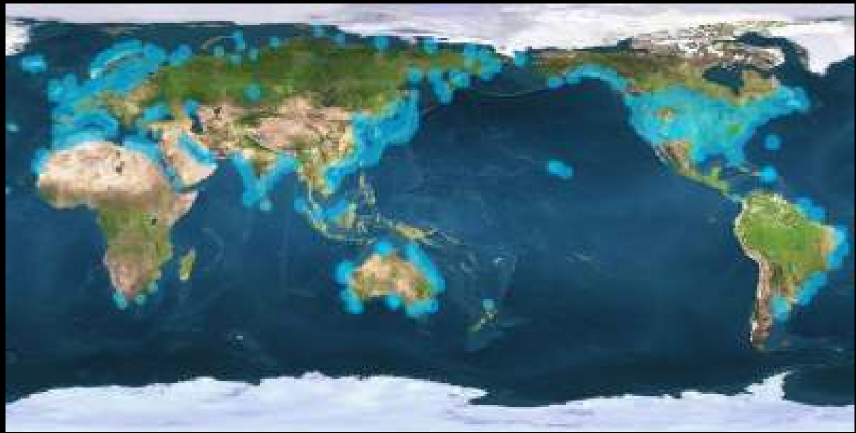
From Wikipedia, the free encyclopedia

Infrastructure can be defined as the basic physical and organizational structures needed for the operation of a society or enterprise, [1] or the services and facilities necessary for an economy to function. [2] The term typically refers to the technical structures that support a society, such as roads, water supply, sewers, power grids, telecommunications, and so forth. Viewed functionally, infrastructure *facilitates* the production of goods and services; for example, roads enable the transport of raw materials to a factory, and also for the distribution of finished products to markets. In some contexts, the term may also include basic social services such as schools and hospitals [3]. In military parlance, the term refers to the buildings and permanent installations necessary for the support, redeployment, and operation of military forces [4].

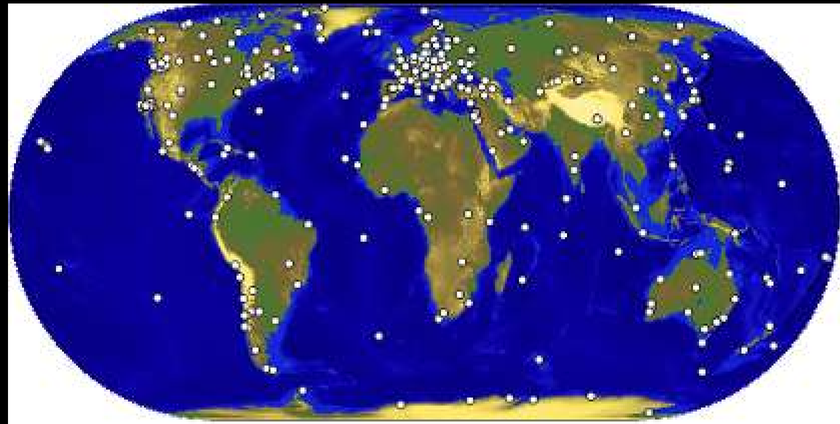
… technical structures or physical networks that support society…

But not all roads, utilities, etc, have same dimensions or capabilities!

Heirarchically organised infrastructure is the norm…



Differential GPS Networks



International GNSS Service

Substantial ground-based infrastructures have been (& will continue to be) established to augment GPS/GNSS accuracy…

Permanent Reference Stations (CORS) are a significant civilian co-investment in GPS/GNSS capability…

Geospatial Infrastructures

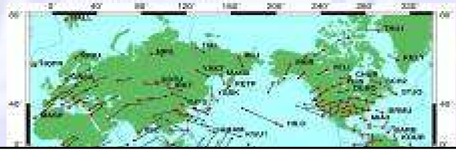
- Spatial Data Infrastructure… *consisting of "layers" of geo-coded* ***information*** *to support the functioning of modern society… data, procedures, governance, standards, etc*.
- Precise Positioning Infrastructure… *passive* ***groundmarks*** *& active* ***CORS*** *to support positioning & mapping within a Datum… augmentation service to enable higher accuracy than standalone GNSS positioning*.
- Geodetic Infrastructure… *technologies, techniques, facilities & services to address the mission of* ***Modern Geodesy****… via access to ultra-accurate & stable reference frames using the tools of Space Geodesy*.

What is ***Modern*** Geodesy?

The primary mission of Modern Geodesy can be defined in terms of the following capabilities:

- Determination of precise global, regional & local 3D (static or kinematic) *positions on or above the Earth's surface, & land surface geometry (e.g. DEMs)*.
- Determination of the Earth's (time & spatially) *variable gravity field.*
- Measurement (& modelling) of *dynamical phenomena*:
  - *Solid Earth (incl. cryosphere)*: surface deformation, crustal motion, GIA, polar motion & earth rotation, tides, water cycle, mass transport, etc
  - *Atmosphere*: refractive index, T/P/H profiles, TEC, circulation, etc
  - *Ocean*: sea level, sea state, circulation, etc

GNSS Precise Positioning Applications



- Surveying & mapping

All require CORS infrastructure

… But how multi-functional? Coverage area? Operators? Service levels? Access conditions?

Monitoring

Rapid Mobile Mapping

Port Operations

- Geodesy/science apps, monitor datum, etc.

Land Surveying

Machine Guidance

Precision Agriculture

- Precise geo-referencing of airborne or terrestrial scanning/imaging sensors

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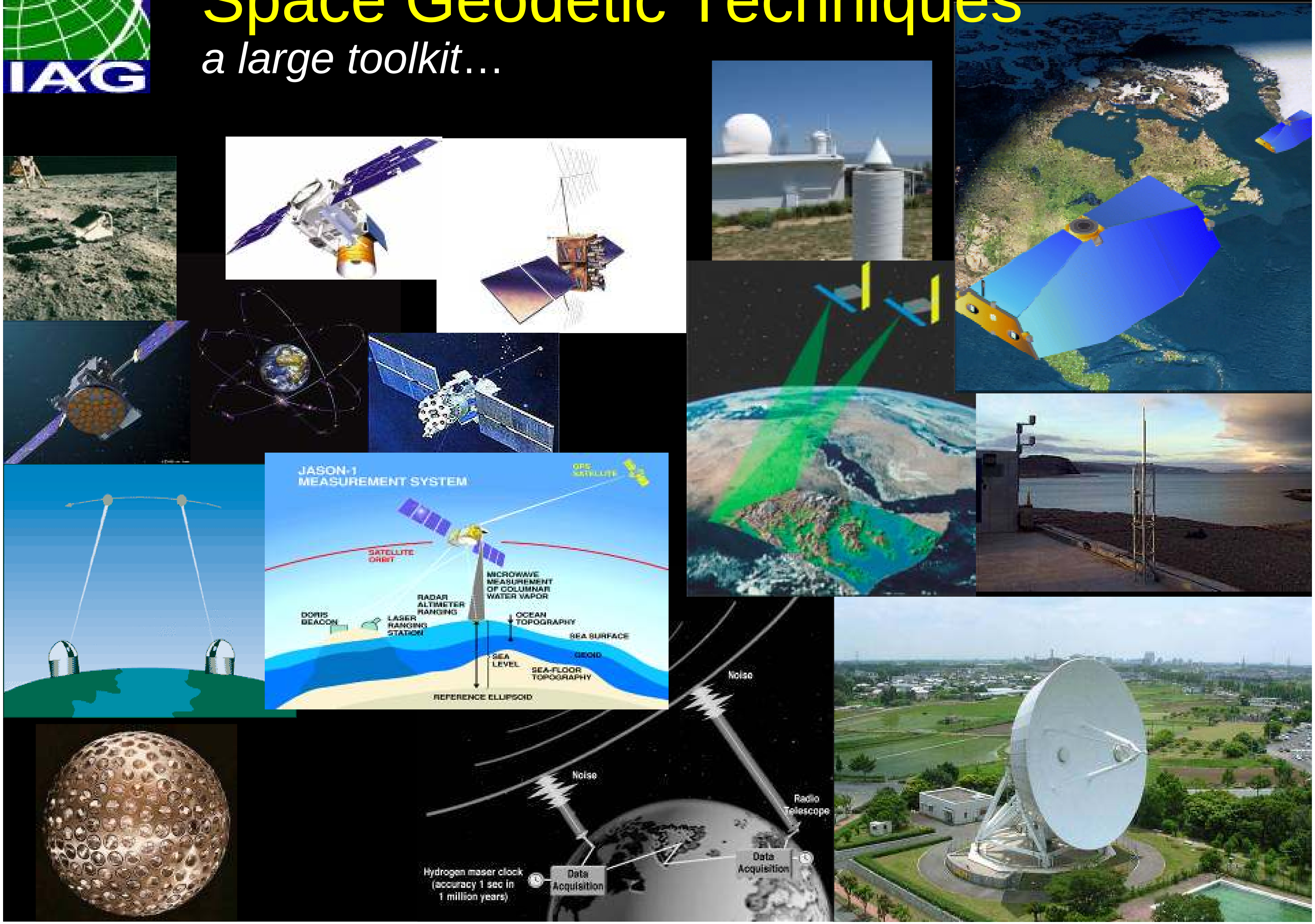
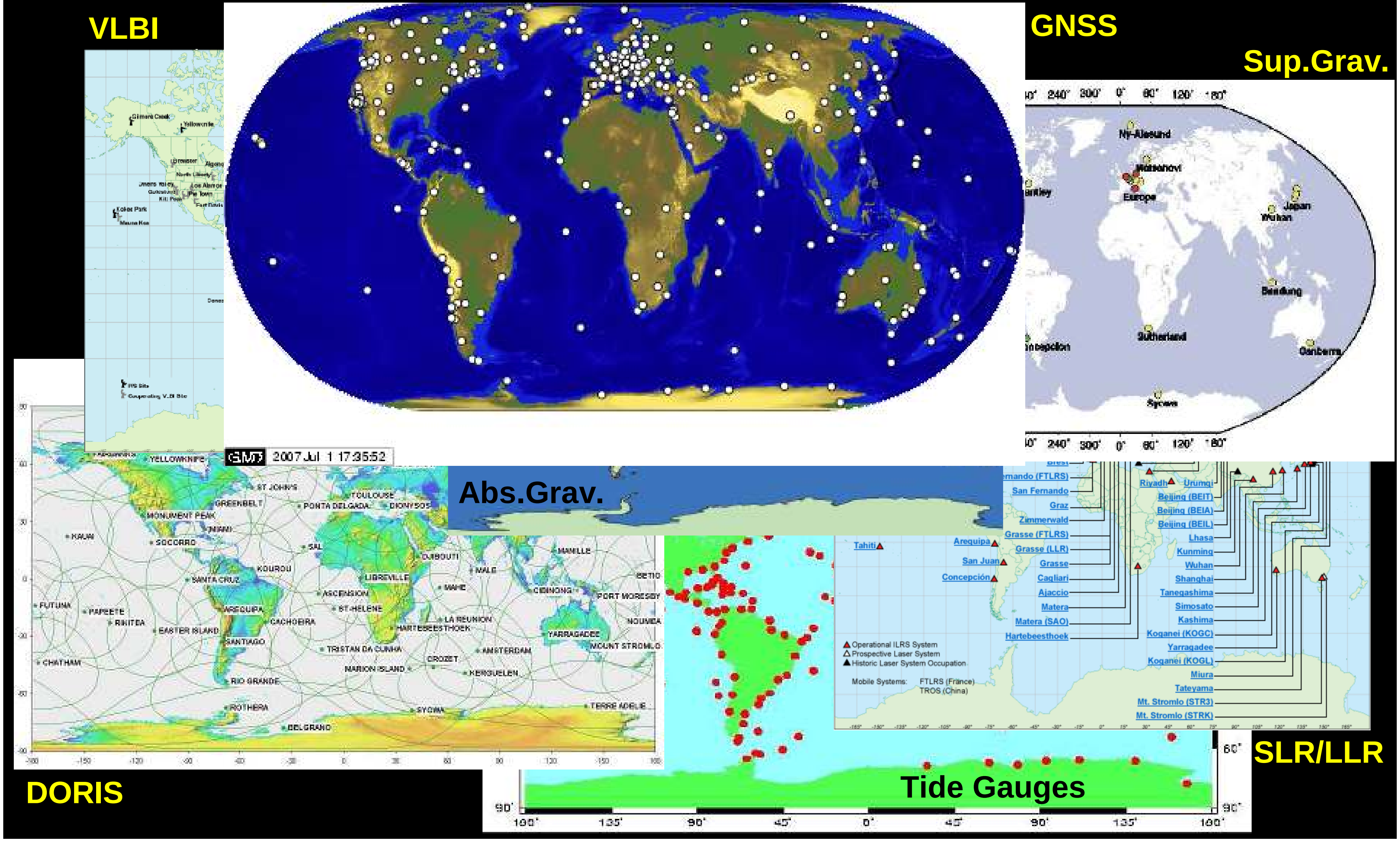
Space Geodetic Techniques

a large toolkit…



Modern Geodetic Techniques

significant ground-based Infrastructure…



IAG Services

Geometry	IERS:	International Earth Rotation and Reference Systems Service
	IGS:	International GNSS Service *(1994)*
	IVS:	International VLBI Service *(1999)*
	ILRS:	International Laser Ranging Service *(1998)*
	IDS:	International DORIS Service *(2003)*
Gravimetry	IGFS:	International Gravity Field Service *(2008)*
	BGI:	Bureau Gravimetrique International
	IGeS:	International Geoid Service
	ICET:	International Centre for Earth Tides
	ICGEM:	International Centre for Global Earth Models
	IDEMS:	International Digital Elevation Models Service
Ocean	PSMSL:	Permanent Service for Mean Sea Level *(1933)*
	IAS:	International Altimetry Service *(in planning)*
Std	BIPM:	Bureau International des Poids et Mesures (Time *1875*)
	IBS:	IAG Bibliographic Service

GGOS:
binds them together

The International Association of Geodesy's

Global Geodetic Observing System (GGOS)

GGOS has the goal of advancing geodetic observing methods for Earth science…
with factor of 10x accuracy increase over coming decade… 1mm accuracy reference frame & stability of 0.1mm/yr.

…

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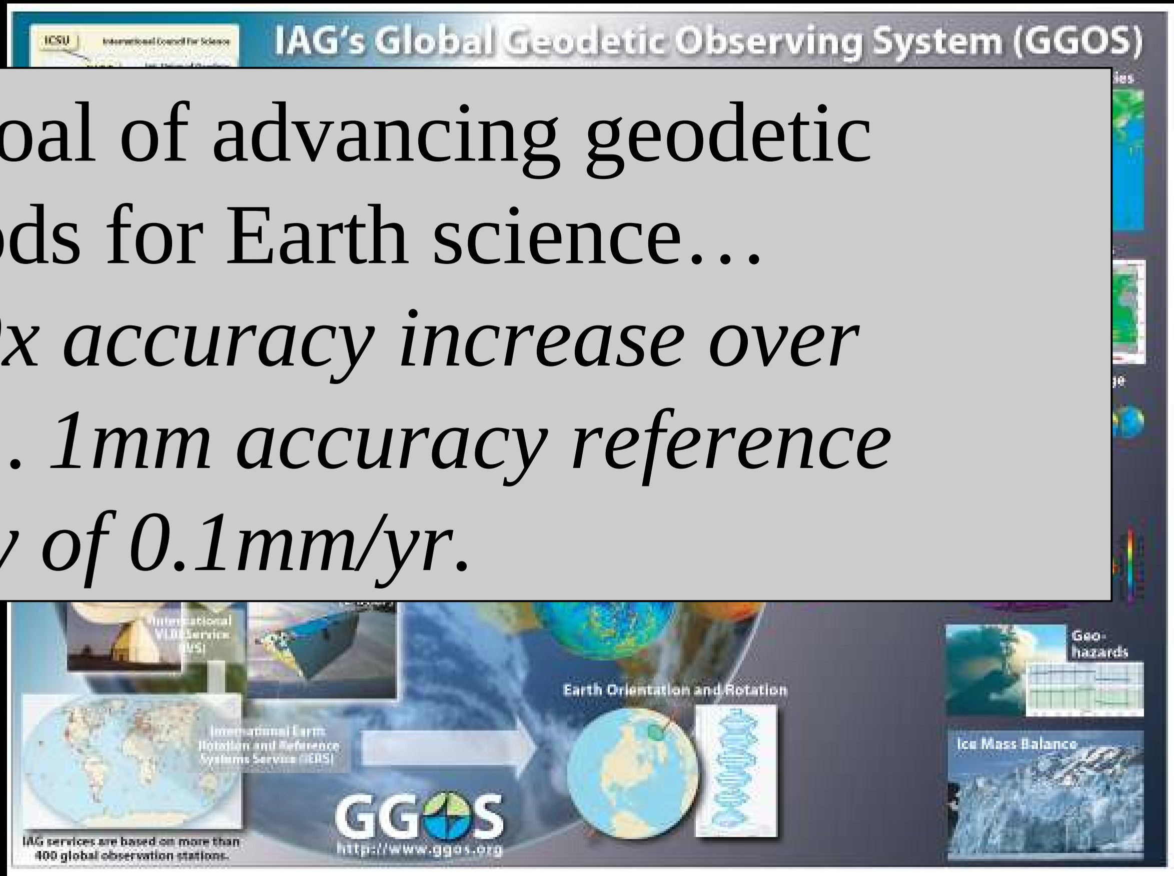
that can detect the “fingerprints” of Global Change…



http://www.ggos.org

GNSS Geodesy/PP: *a widening "gap"?*

- GNSS is an extremely powerful **Precise Positioning** technology… *but **cm-level accuracy is generally adequate**… high productivity, cost-effectiveness & ease-of-use are the key requirements… need appropriate rollout of Real-Time(RTK)-capable CORS*.
- GNSS is the critical technology for **Modern Geodesy**, essential for delivering **ppb (relative) positional accuracy**… *requiring a "state-of-the-art" global GI so as to deliver reliable, high quality geodetic products to science (& the community in general).*

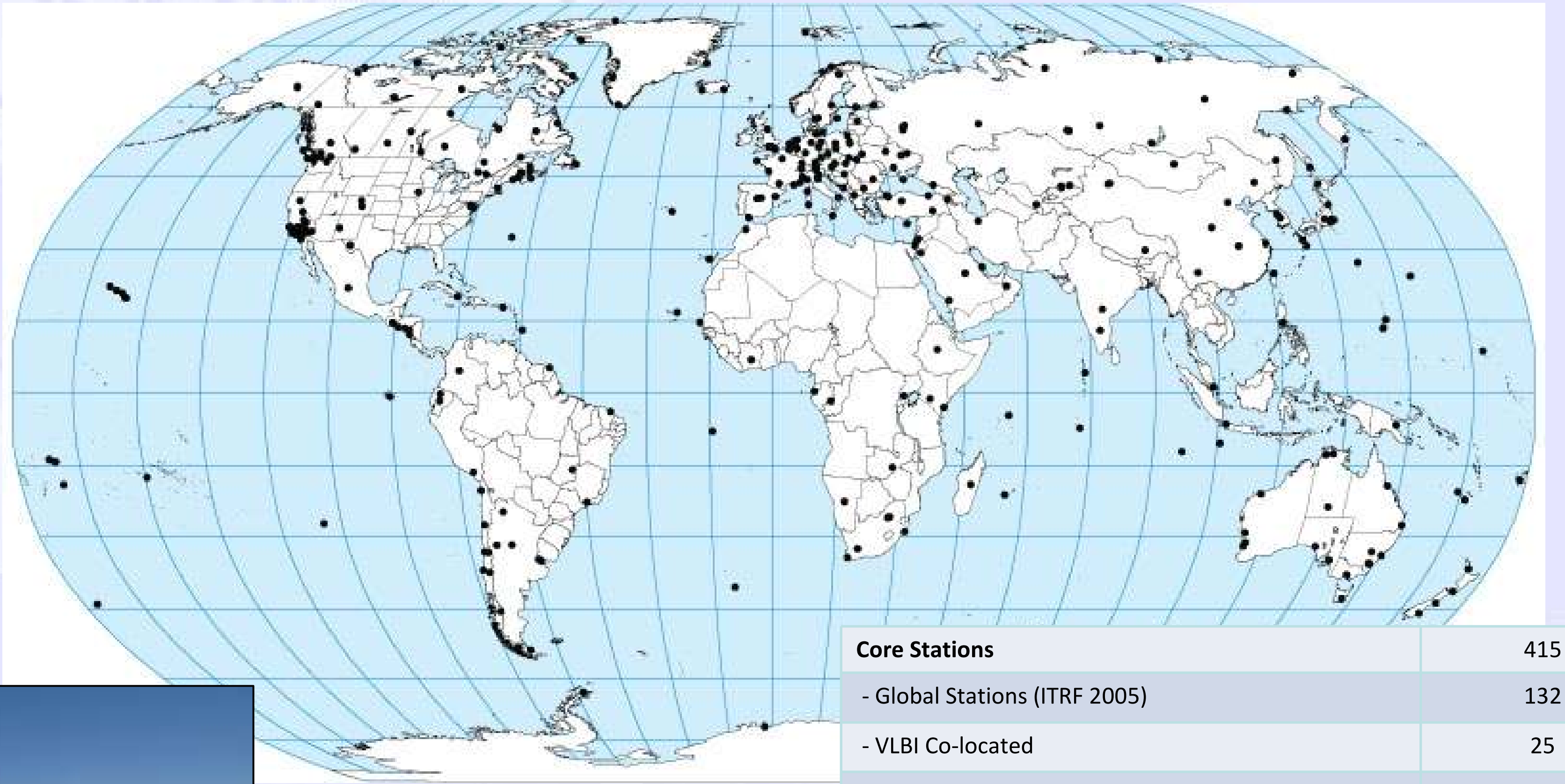
The first civilian application of GPS was to establish "geodetic control"… *but how can we reconcile the (sometimes divergent) trends in Precise GNSS Positioning into a **unified model** of GNSS CORS infrastructure?*

The "top down" infrastructure model is based on densification of the global IGS network and adoption of the ITRF2008…

The "bottom up" approach focuses on the unification of regional, national or local CORS networks (government or private)…

Both approaches are valid… however a seamless connection between GI and PPI will be a challenge… not the least for a number of non-technical reasons…

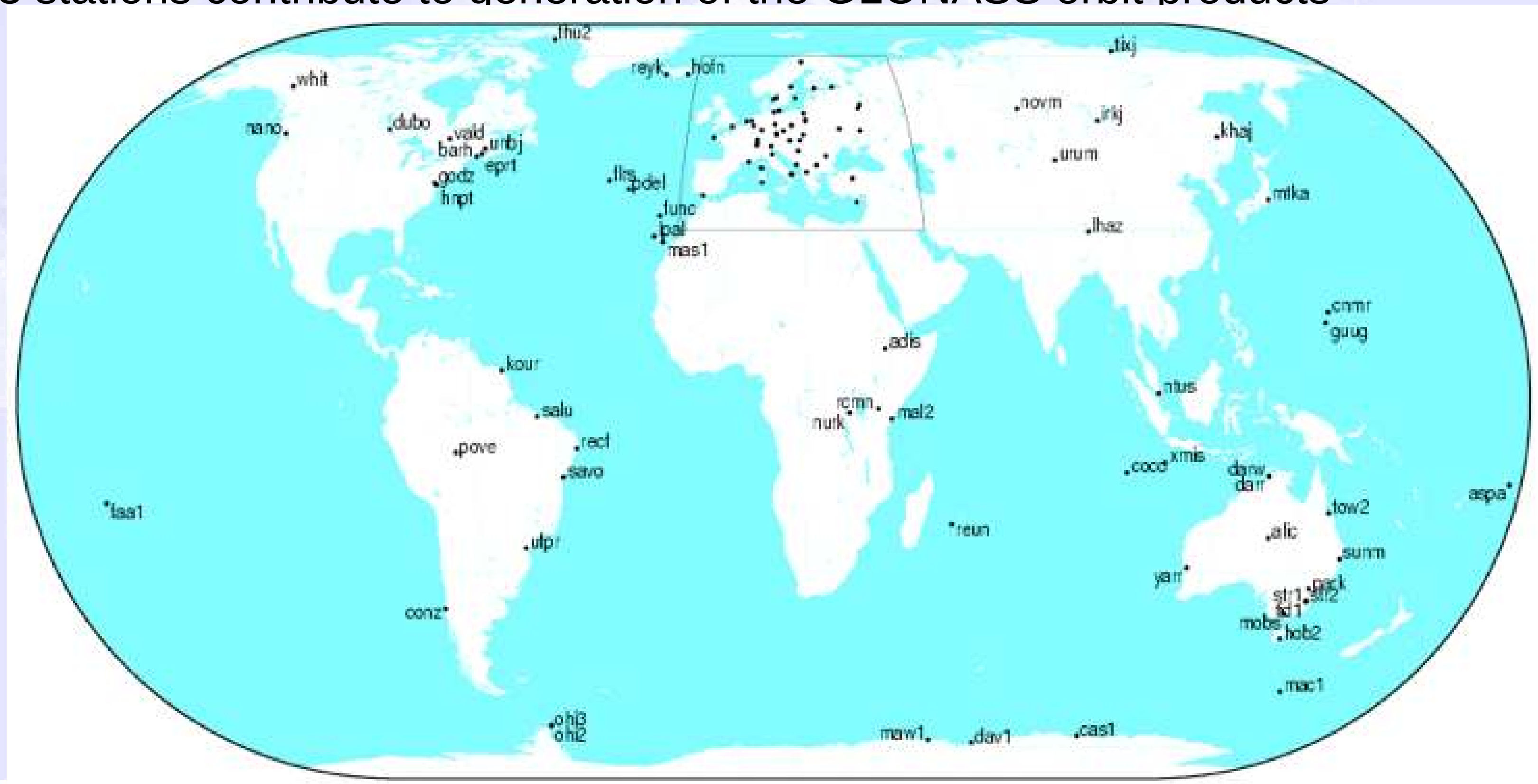
IGS Tracking Network



Core Stations	415
- Global Stations (ITRF 2005)	132
- VLBI Co-located	25
- SLR Co-located	37
- Doris Co-located	55
Project Stations or Experimental Capabilities	
- Timing stations	80
- Reprocessing campaign 2003-2007	667
- Tide Gauge Co-located	103
- Multi GNSS	93
- Real-time	120

IGS GPS+GLONASS Activities

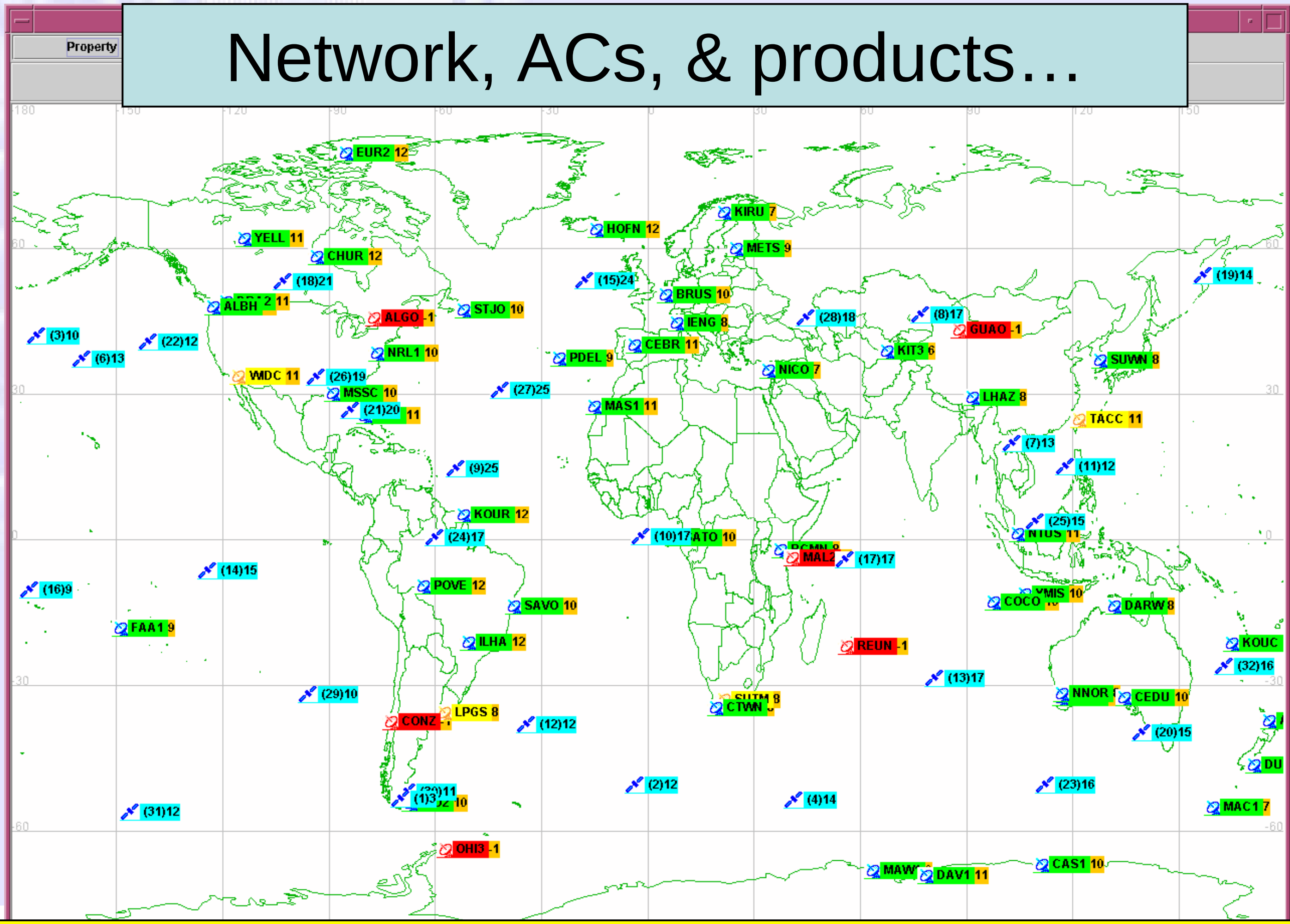
- GLONASS orbits are currently one of the IGS products
- 93 stations contribute to generation of the GLONASS orbit products



IGS network & ACs need to be upgraded to track next generation GNSS (and generate new products)…

Real-time IGS Network… *Pilot Project*

Network, ACs, & products…

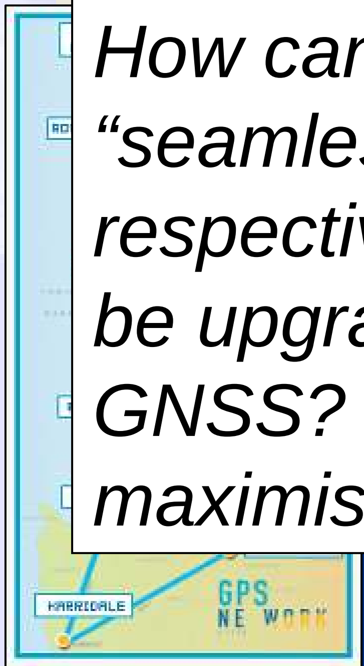


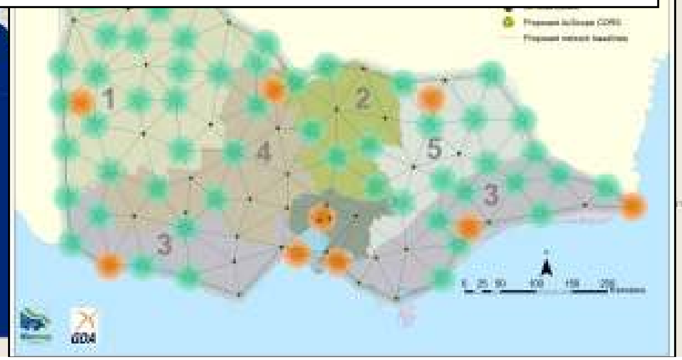
RT-IGS will have to connect with GNSS CORS Infrastructure at regional, national & local levels…

Australia's GNSS Infrastructure

But there are many (hundreds to thousands) of additional GNSS reference stations…

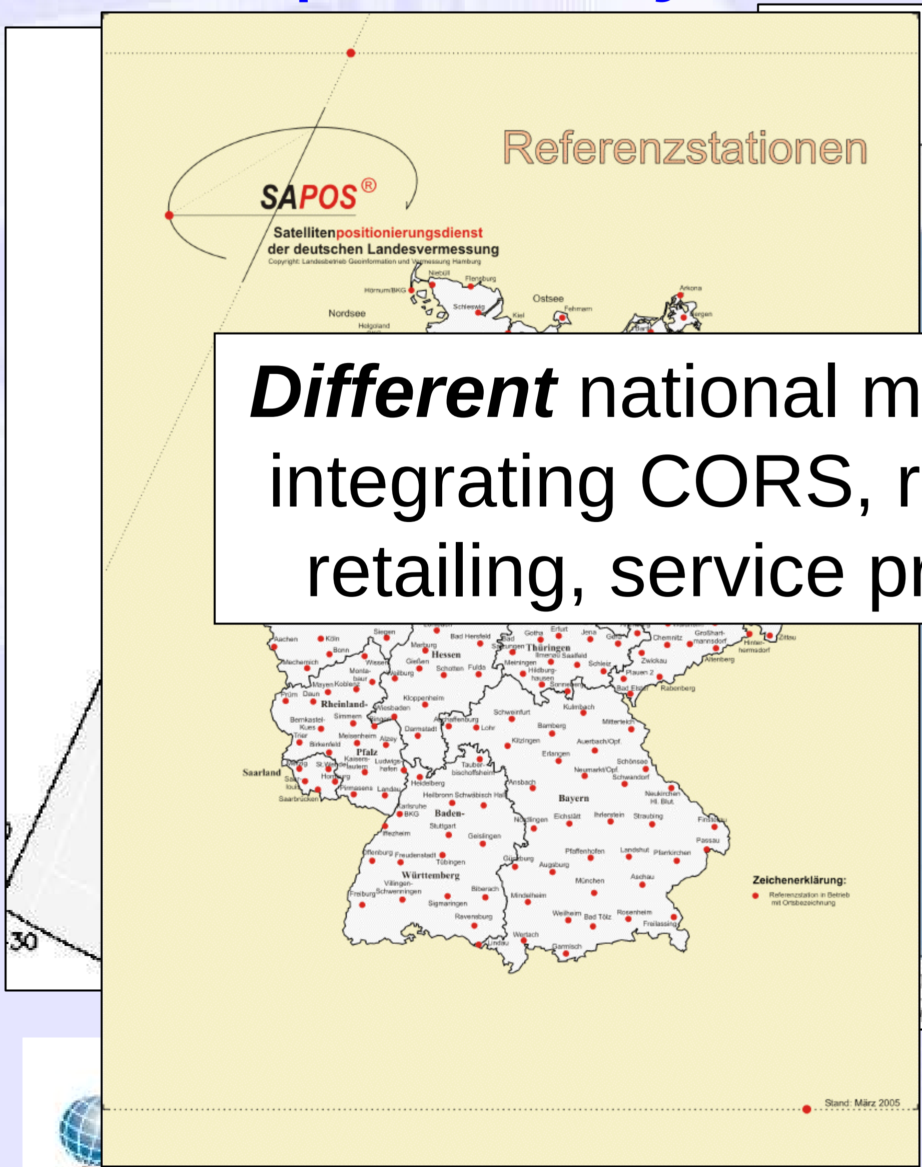
How can they be best integrated to provide "seamless" services? What are the roles of the respective CORS owners/operators? How will they be upgraded to deliver PP services with "next gen" GNSS? How to minimise duplication? How to maximise QoS?

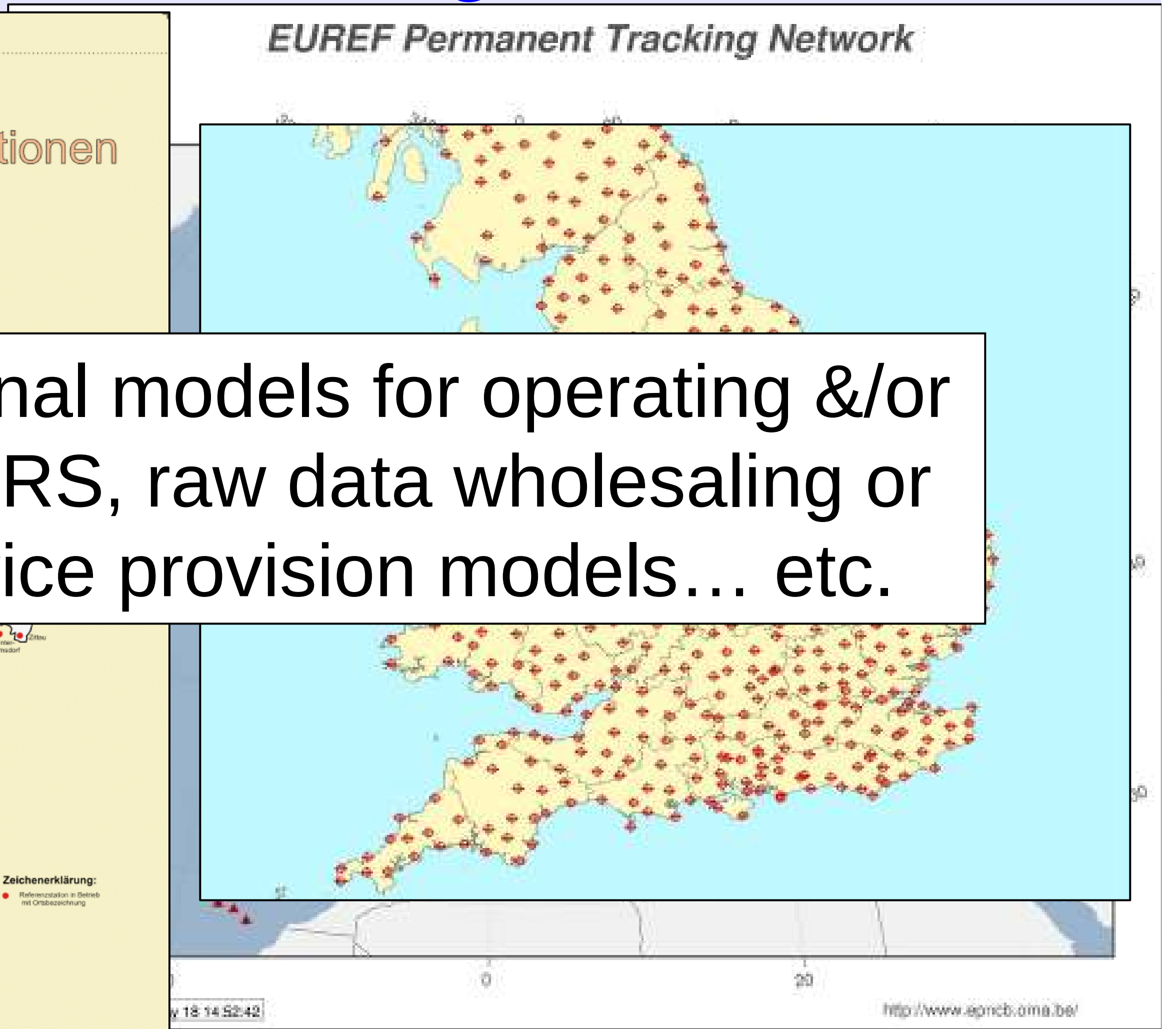




AuScope GNSS Stations

Europe…*are you better organised?*





Different national models for operating &/or integrating CORS, raw data wholesaling or retailing, service provision models… etc.

Towards a "Unified Model" for GNSS CORS…

Some distinguishing characteristics of **Geodetic** (science) & **Precise Positioning Infrastructures** (govt & commercial):

- Reference frame issues
- Monumentation
- GNSS receiver technologies
- Data access policies
- Operations & business models
- Products & services

Reference Frame Issues…

GNSS GI

- International Terrestrial Reference Frame (ITRF) definition, maintenance & access, *to support scientific applications*
- Requires 4D position-time series integrity
- Core sites collocated with other space geodesy stns
- *Sparse CORS network is sufficient*

GNSS PPI

- ITRF &/or national datums, with stability monitoring
- Local datum is sufficient for some PP applications
- WGS84 “confusion”
- Variety of ways to account for “dynamic datum”
- Typically with minimal (local stn) stability monitoring
- Dense (& perhaps uneven) network coverage

Multi-Tiered GNSS Infrastructures?

GNSS CORS infrastructures could be *heirarchical*:

1) *Tier 1* are the IGS-class stations… *possibly equipped with "system of system" (SoS) multi-GNSS receivers (perhaps software-configurable), with best monumentation, etc*., to support mission of Modern Geodesy.
2) *Tier 2* are the primary national geodetic CORS… *COTS multi-GNSS receivers, with best instrumentation,* providing foundation for Datum and National PPI.
3) *Tier 3* are the state (or secondary) and private CORS… "*sub-"SoS Rxs, supporting many RTK users, using variety of operational models, and fit-for-purpose installations*.

Mimics classical heirarchical control network structure… *but are there clear standards or specs to differentiate each "tier"?*

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Monumentation Issues…

GNSS GI

- *Ultra-stable monument & site*
- Expensive to build
- Best data quality (low multipath, RFI)
- IGS standards/guidelines
- Antenna/radome specs
- Long-term commitment to station operations
- *Continuity valued above all*

GNSS PPI

- *"Fit-for-purpose", cost-effective*
- Variable guidelines
- Siting criteria influenced by dominant user application
- *Very different agency or company practices*
- Likelihood for duplication
- Possibility of defining jurisdictional "Stds&Specs"

Geodetic GNSS Monumentation

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GNSS PPI Monumentation

GNSS Receiver Issues…

GNSS GI

- Multi-GNSS receiver
- *Multi-frequency, top-of-the-line receivers*
- Software-based, or custom-design receivers(?)
- Reluctance to change instrumentation
- Industry standard & *scientific outputs*

GNSS PPI

- Multi-GNSS, & other options
- Possibility for lower cost, dual-frequency receivers & antennas, within “mixed” networks
- Upgrade cycle driven by market/user needs
- *Industry standard outputs*, e.g. for RT operations
- More rapidly changed

From GPS to Next Generation GNSS…

GPS III

ГЛОНАСС

GALILEO

COMPASS

+

QZSS

IRNSS

2013-18: 4x number of satellites, 6x number of signals!

Profound impact on users, but requiring upgrade of user equipment & reference networks; communications, formats & standards; field techniques, modelling, algorithms, products…

including the GI and PPI

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CORS Receivers…

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Data Access Issues…

GNSS GI

- *Raw data & derived products freely available through IGS*
- Increasingly RT data streams, in addition to RINEX, becoming available
- Some project/region-specific data restrictions for “exclusivity” or security reasons
- Challenge integrating data with non-IGS CORS

GNSS PPI

- *Variable data access policies (or restrictions)*
- Data may be provided free for “research purposes”
- Derived products or services offered on commercial basis
- Raw RT data may also be viewed as commercial, esp. from private CORS
- Onerous data policies or high access charges can drive duplication of CORS

Operations & Business Model Issues…

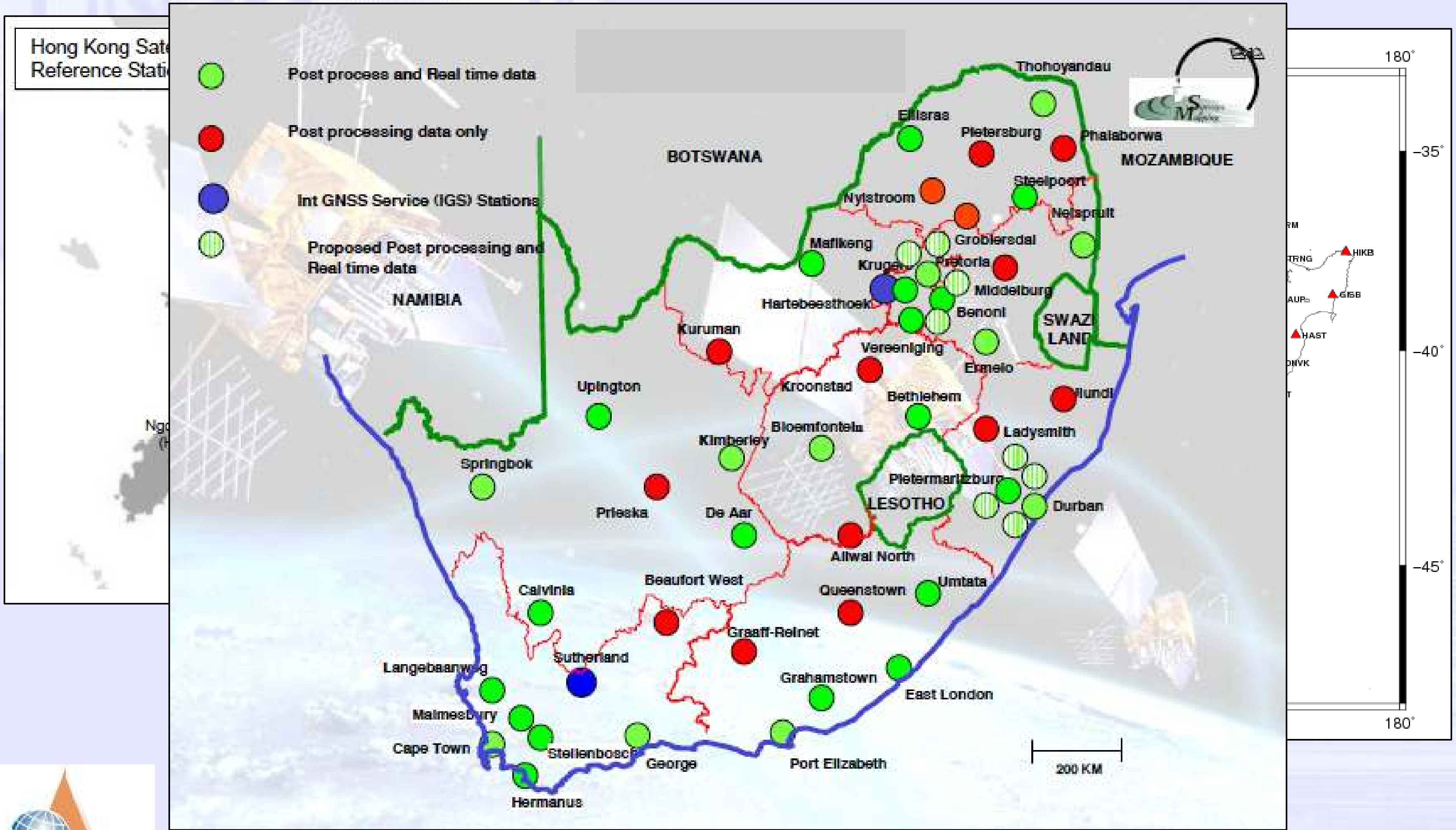
GNSS GI

- *"Best effort" operations*
- Not commercial
- Distributed governance
- Funded by national agencies for science
- IGS/IAG plays coordinating role
- Increased service levels (esp. accuracy)

GNSS PPI

- *Highly variable, from free-to-air to full commercial*
- *Variety of government agency roles*, from providing basic PP infrastructure, to wholesaler or retailer of raw data or services
- Industry- or geographically-organised service providers
- Variety of fee models

GNSS PP Infrastructure…*free*



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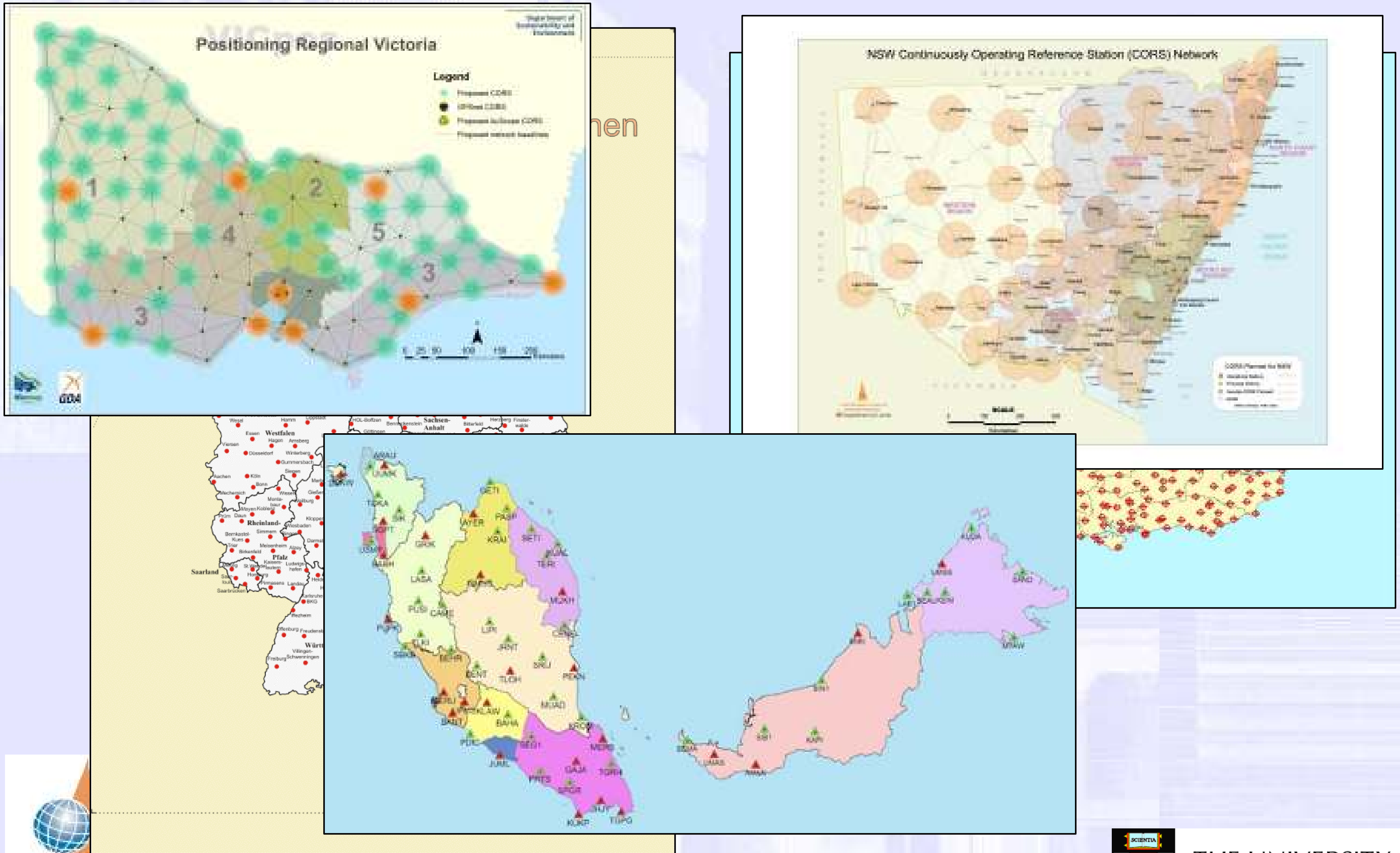
GNSS PP Infrastructure…*commercial*



national, state, local networks

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Products & Services Issues…

GNSS GI

- *IGS is product generator*
- Independent (& redundant) analysis centres
- Plus individual researchers
- Continuous product improvement is a driver
- Predominantly post-processed using “scientific software”
- RT GNSS geodesy a future goal
- Influences government policies re scientific CORS

GNSS PPI

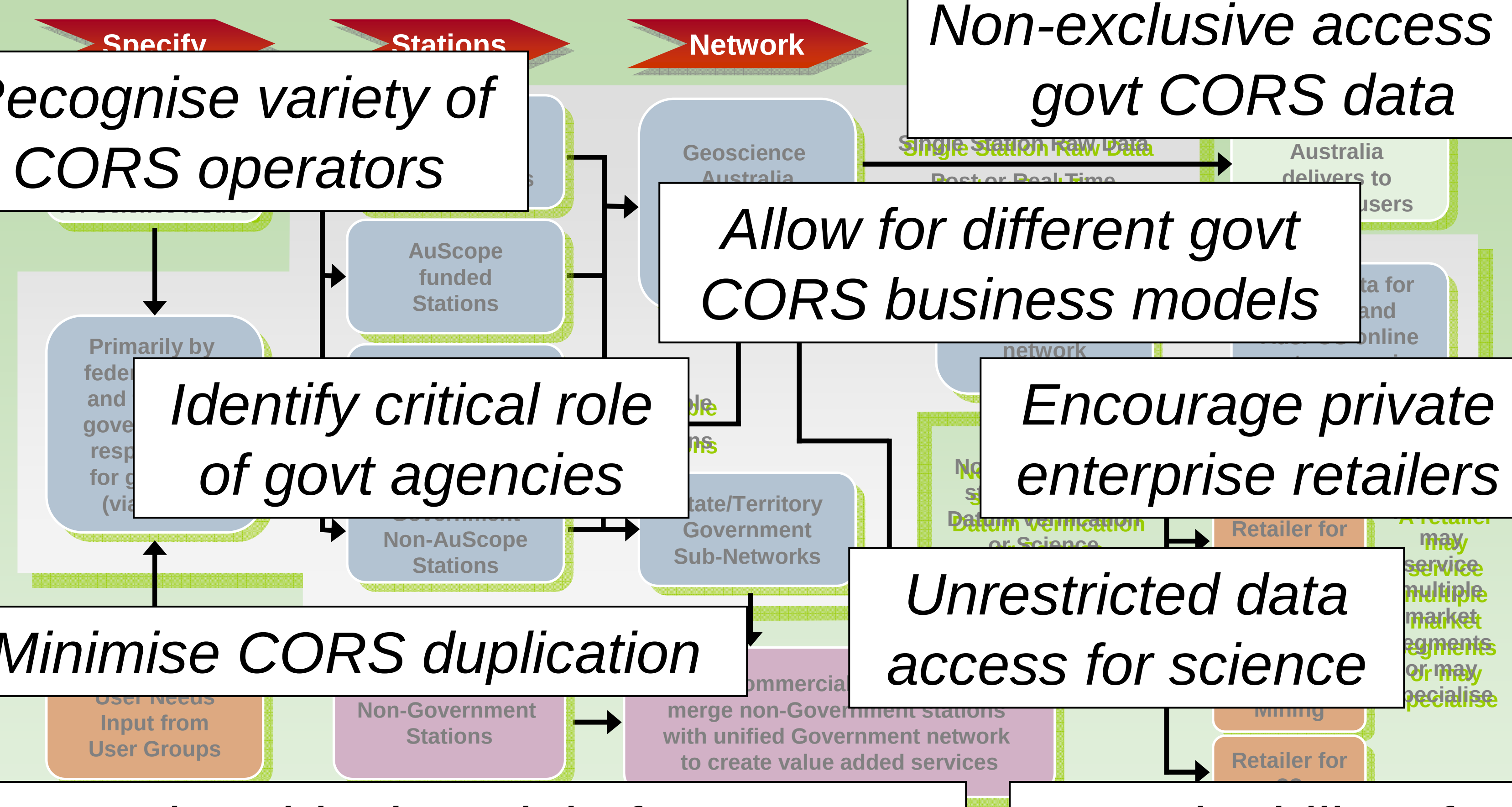
- *Market driven*
- Variety of value-added (e.g. RTK) services
- Possibly using same CORS
- Based on commercial SW
- Variety of business models
- Variety of product “channels”
- Variable quality assurance
- Interoperability kept to a minimum
- Innovation is the “market differentiator”

GI/PPI: role for everyone - *the Australian example*…

Specify	Stations	Network	Process	Deliver
Specify System	**Own Stations**	**Network the Data**	**Process Network**	**Deliver Service**
• Target Density, Coverage Reliability and Availability • Site Quality • Equipment Quality • Geodetic Reference Frame • Data Services Produced • Data Access Policy	• Site Selection • Site Construction • Equipment Purchasing • Station Data Comms • Site Maintenance • Equipment Replacement Cycle	• Data Comms from Network Stations • Control Centre • Data Archive	• Copy of Network • Data Processing (for RTK) • Production of Data Streams • Distribution of Data Streams • Data Wholesaling • Retailer Support	• Retail Sale of Data Products • Marketing • Rover Equipment support • End User Support • Liaison with User Comms Providers

"An organisational model for unified GNSS reference station network for Australia", M. Higgins, J. Spatial Science, Dec 2008

GI/PPI: role for everyone - *the Australian example*…



Non-exclusive access to govt CORS data

Recognise variety of CORS operators

Allow for different govt CORS business models

Identify critical role of govt agencies

Encourage private enterprise retailers

Unrestricted data access for science

Minimise CORS duplication

Heirarchical model of QC, stn stability monitoring, stds & specs, national datum connection

Sustainability of core GI/PPI investment

"An organisational model for unified GNSS reference station network for Australia", M. Higgins, J. Spatial Science, Dec 2008

Benefits of GNSS PP(RTK) in Australia…

- 2008 study found productivity gains with potential cumulative benefit AUD$73 to $134 billion over next 20 years - *in agriculture, construction and mining alone*.
- *Additional* cumulative benefit AUD$32 to $58 billion, from a *coordinated* rollout of PPI within GI framework.
- Also, significant *environmental* benefits, such as reduced carbon footprint, through greatly improved fuel efficiency.

"Economic benefits of high resolution positioning services", Allens Consulting Group, for CRC-SI & Vic. DSE, Nov 2008, download: http://www.crcsi.com.au/uploads/publications/publication_348.pdf

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Take home messages…

- CORS infrastructure is *civilian co-investment* to support PP applications.
- There is a widening range of PP GNSS techniques, facilities & services… *multi-tiered CORS infrastructure is/will be a reality.*
- Many more CORS networks will be established… *on a variety of scales, by variety of operators.*
- "Next gen GNSSs" can be the catalyst for a *new beginning.*
- Geodetic GNSS is vital for future geodesy… *but need upgrade of IGS network & ops, & more national agencies' support.*
- "Unification Model" of heirarchical GI/PPI may be needed to maximise benefits of GNSS technology… *better governance, clearer PP guidelines, less infrastructure duplication, increased innovation, & accelerated GNSS user uptake.*

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Thank You!