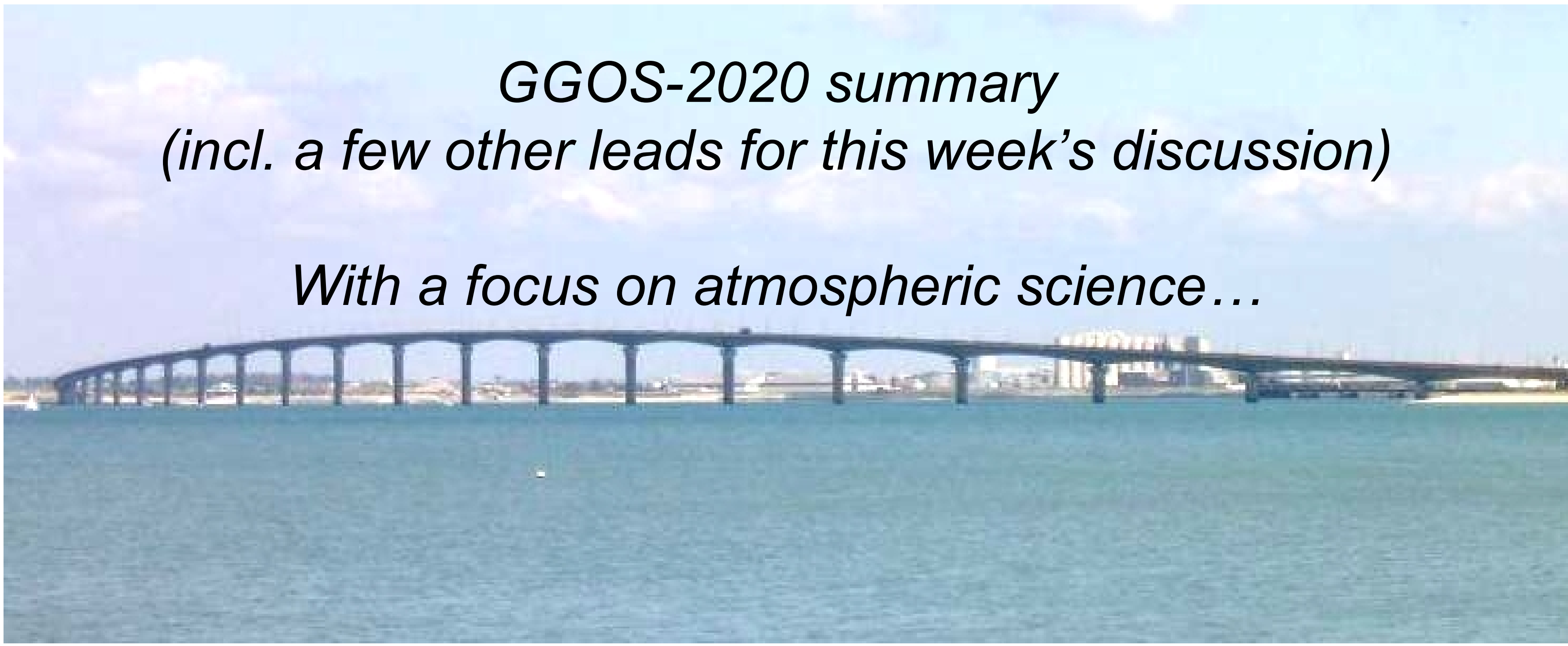
GGOS: a Service for the other Earth Sciences



GGOS-2020 summary
(incl. a few other leads for this week's discussion)

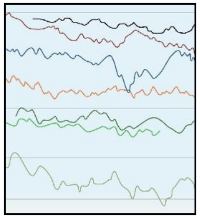
With a focus on atmospheric science…

P. Poli

Challenges for Earth sciences (a selection)

- **Better understand the water cycle**
  - In particular, the atmospheric water part is still poorly observed, but crucial for human life (crops, drinking water)

  ➔ *Requires more/better observations of the atmospheric water vapor*



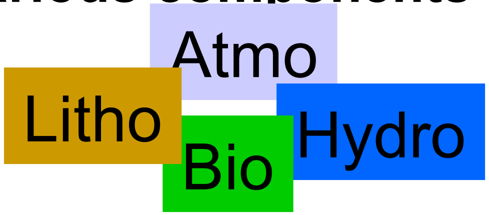
- **Better understand climate variations**
  - Ensure break-free, long time series of observations, not subject to contamination by weather-dependent measurement errors

  ➔ *Requires measurement systems relying on absolute calibration*

- **Better understand the atmospheric vertical coupling**
  - Transfers of energy between the lower trop. and the ionosphere

  ➔ *Requires ionospheric measurements*

- **Better understand the interactions between the various components of the Earth system**
  - Consolidate atmosphere/ocean/ice/biology/hyrology observations/models for interdisciplinary research



  ➔ *Requires consistent observation and modeling references throughout geosciences*

Three roles w.r.t. the other Earth (Atmospheric…) Sciences clearly identified in GGOS-2020

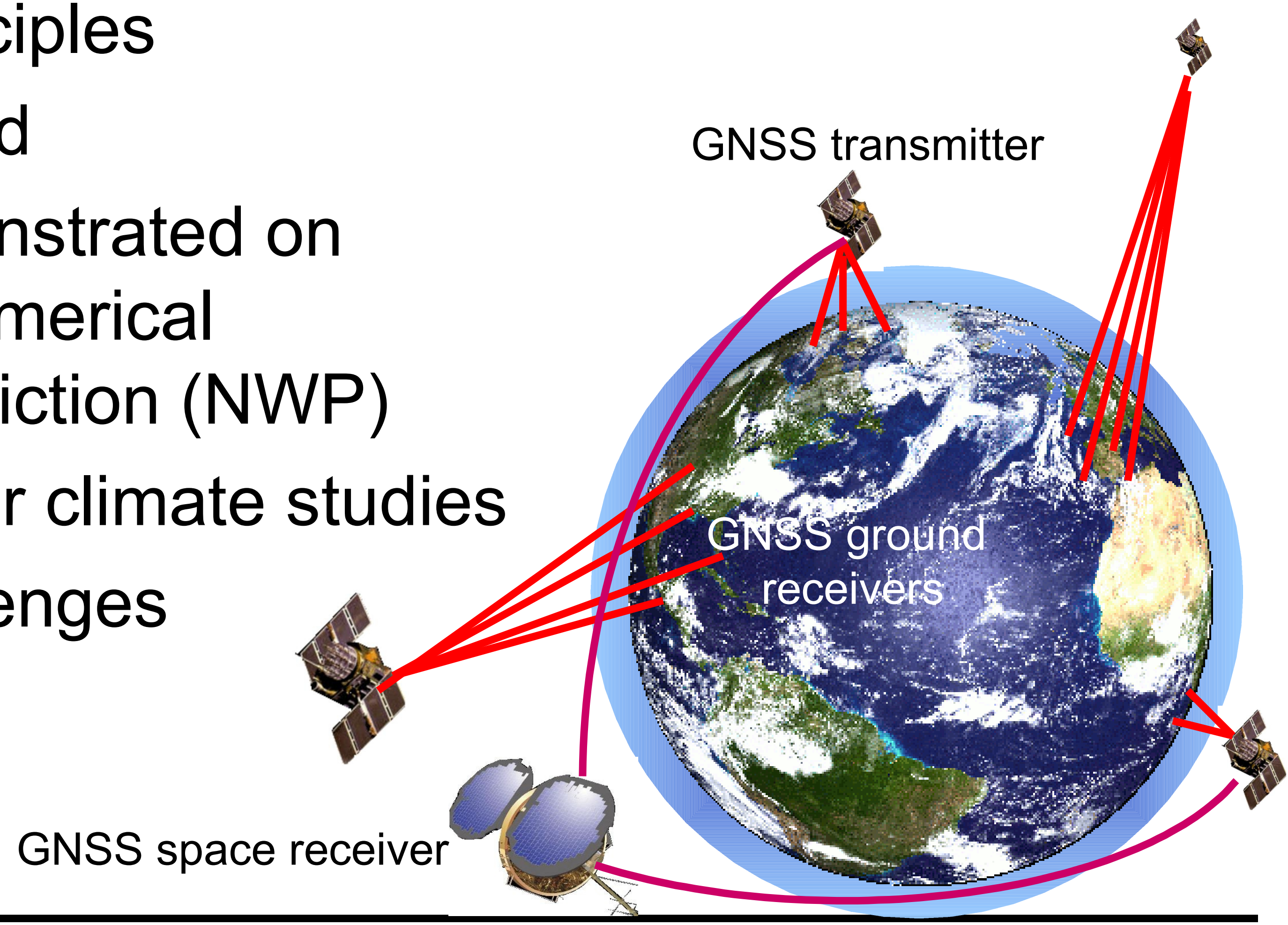
1. A source of observations of the atmosphere and the ionosphere

3. A reference for geo-locating all scientific, systematic observations of the Earth system

5. A reference to be used in fluid Earth system modeling

1. GGOS: a source of observations of the atmosphere and ionosphere

- Sensing principles
- Data collected
- Impact demonstrated on improving numerical weather prediction (NWP)
- Future use for climate studies
- Further challenges



Geodesy (Atmospheric) Sensing principle

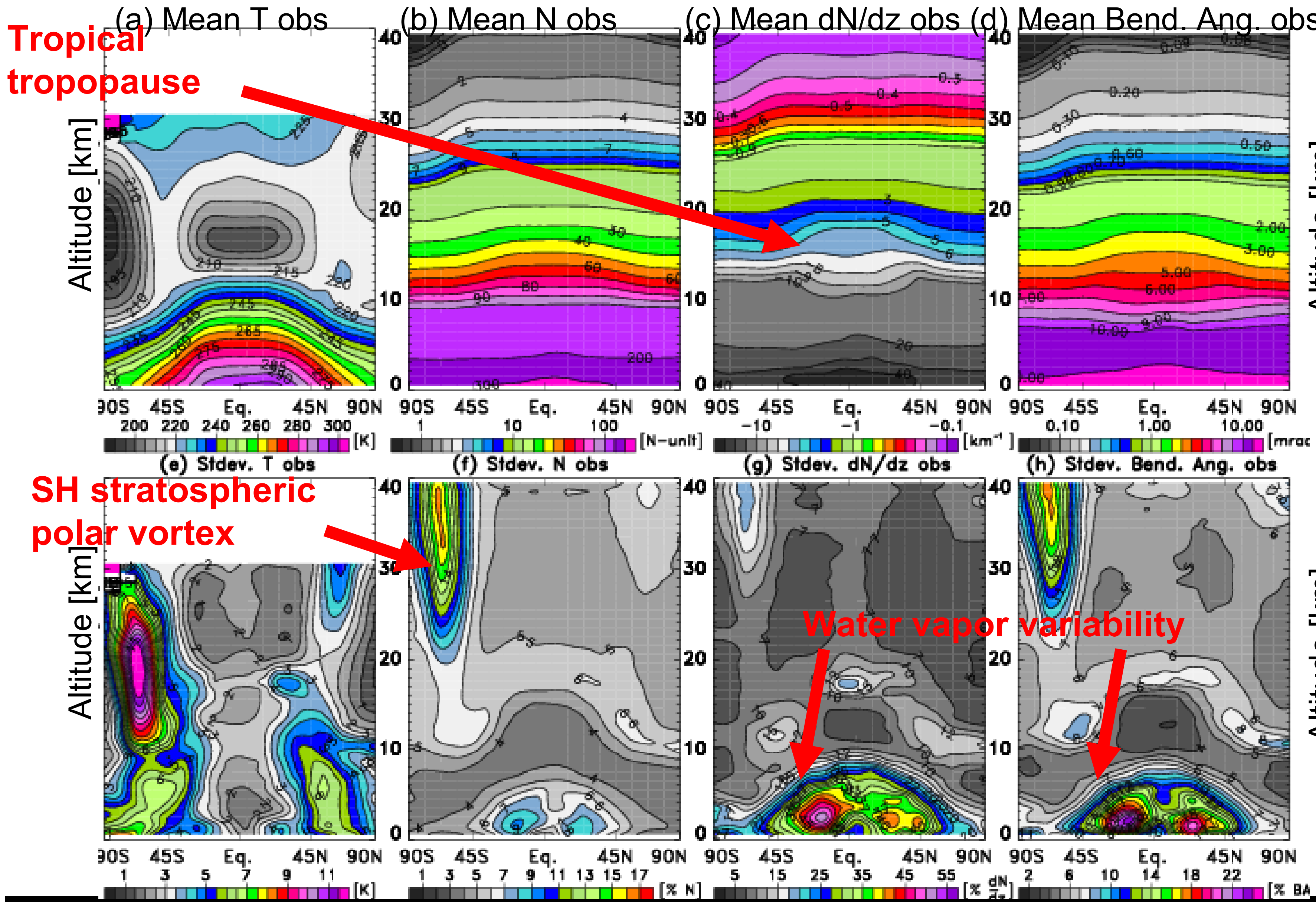
- Geodetic signal transmitters/receivers (GNSS, DORIS, Lasers, VLBI) send/receive EM waves which are refracted/slowed down upon travel in the neutral atmosphere:
  - Physical characteristics (*Pressure, Temperature, Water vapor*) can vary significantly over small horizontal and vertical scales – <u>especially water vapor</u>
  - Physical laws relate physical characteristics and atmospheric index of refraction *n* (non-dispersive at radio freq.)
- Knowing the relative positions of transmitter/receiver, with good knowledge of the wavelength, and correcting for other sources of signal/error (differential motion, relativistic effects, ionosphere)
  - Atmospheric-induced delays can be retrieved
  - Using the physical law that relates *n* with *P*, *T*, *e*, one can retrieve atmospheric characteristics using additional assumptions

What has changed recently (last 2 years)

Bridging operational Geodesy & Meteorology

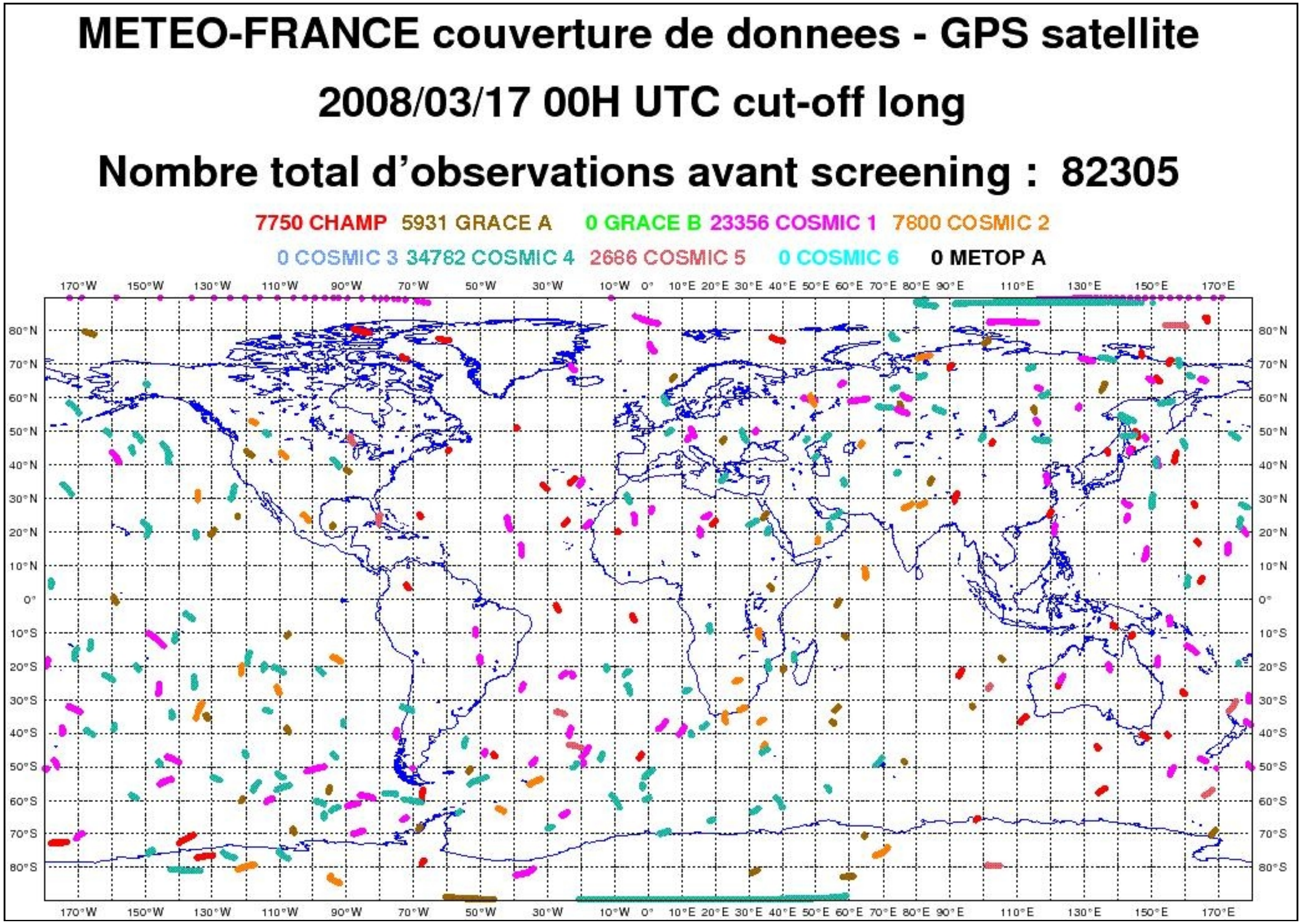
1. GNSS atmospheric-induced delay data from the geodetic community have become available in so-called « near-real-time » (<3 hours after measurement)
   - Regional networks of ground-based GPS: ZTD data (➔ water vapor)
   - GPS radio occultation experiments on various satellites (CHAMP, GRACE, F3C): Bending angle data (mass field+w.v.)
2. Operational meteorology has started using these atmospheric GNSS products
   - Algorithms extract the atmospheric signal from the noise (variational data assimilation ~ a filtering process)
   - Operational meteorology has developed algorithms to trust the GPS RO data as ‘anchors’ for bias correcting other sources of observations (no other data type except radiosonde enjoys that status)

Static view: 1 week of FORMOSAT-3/COSMIC data Oct'06



METEO FRANCE
Toujours un temps d'avance

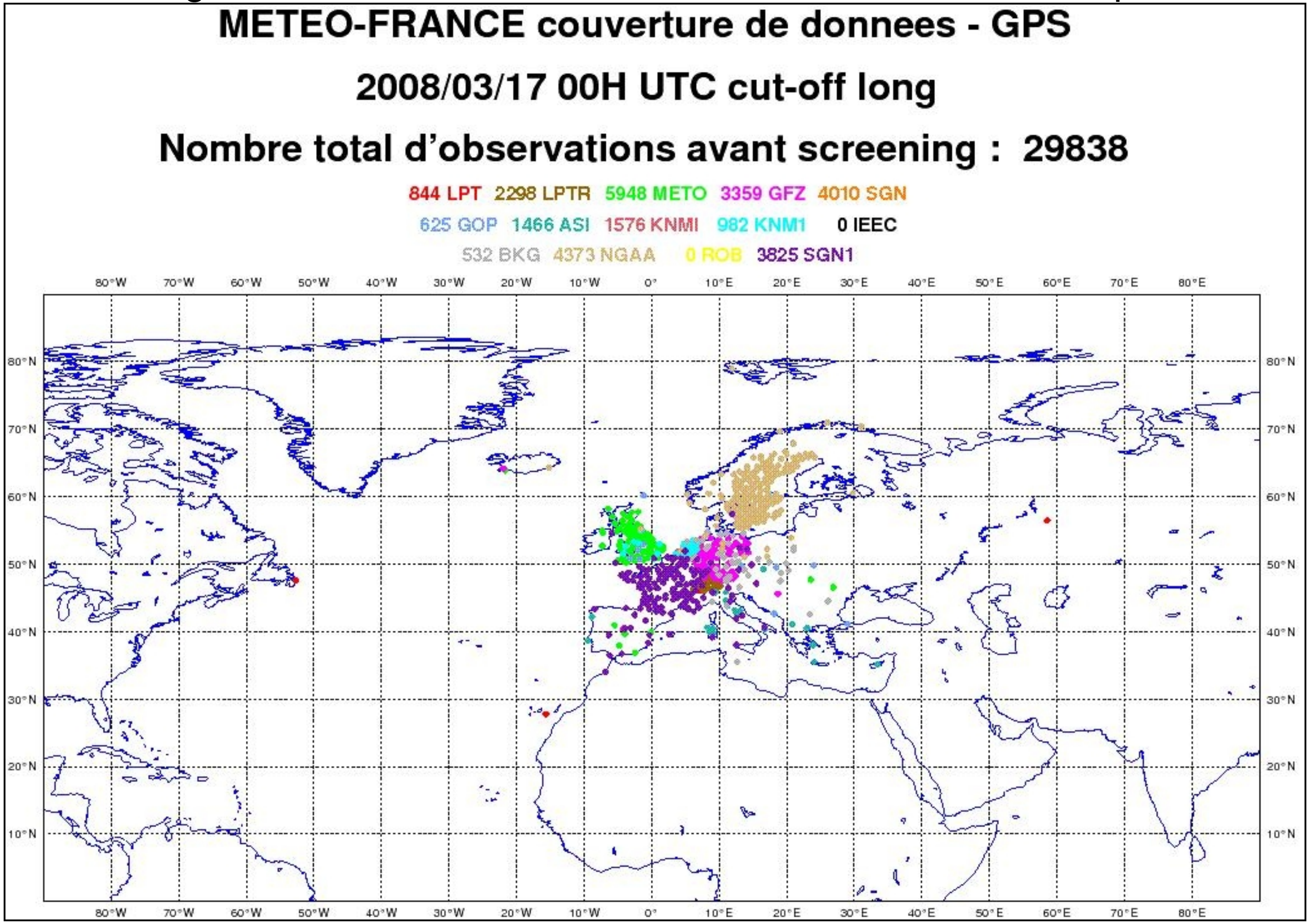
Example of 6-hour coverage for GPS radio occultation data



Meteo-France DPREVI/COMPAS/CONTROLE

Example of 6-hour coverage for European ground-based GPS data

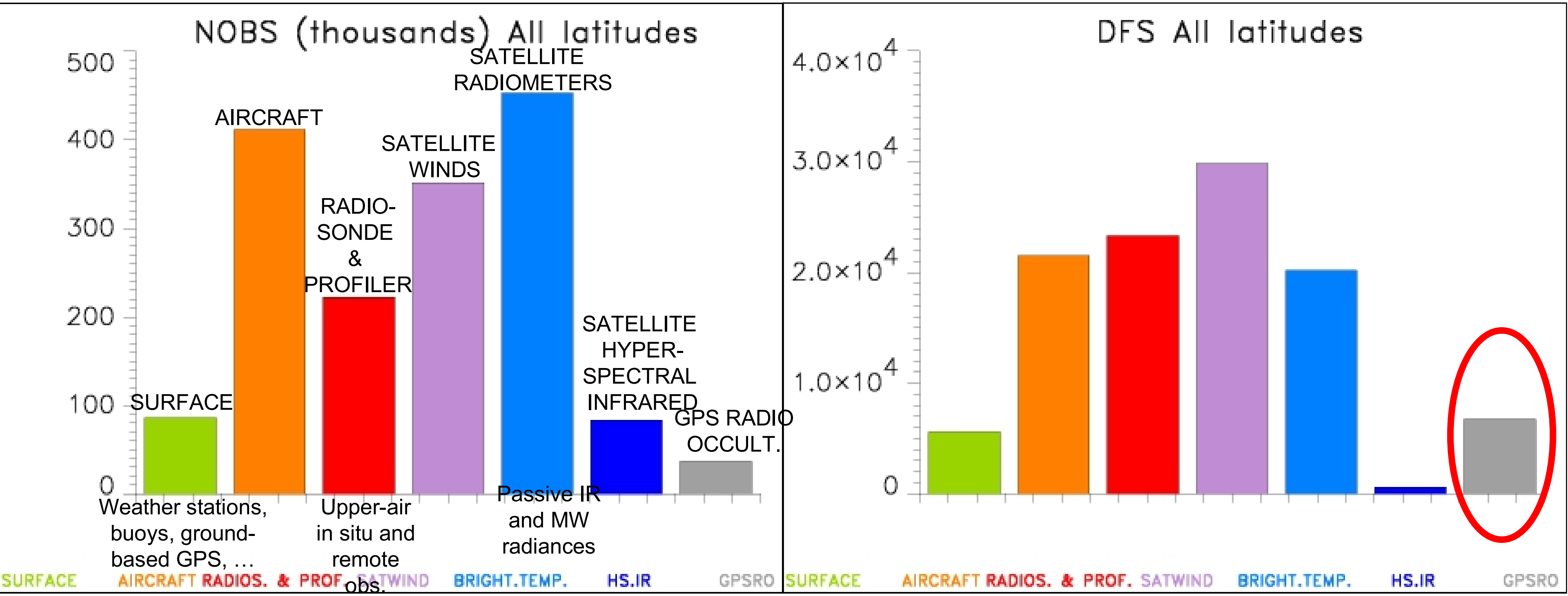
Note: no other ground-based GPS data are available in NRT to European weather centers



Meteo-France DPREVI/COMPAS/CONTROLE

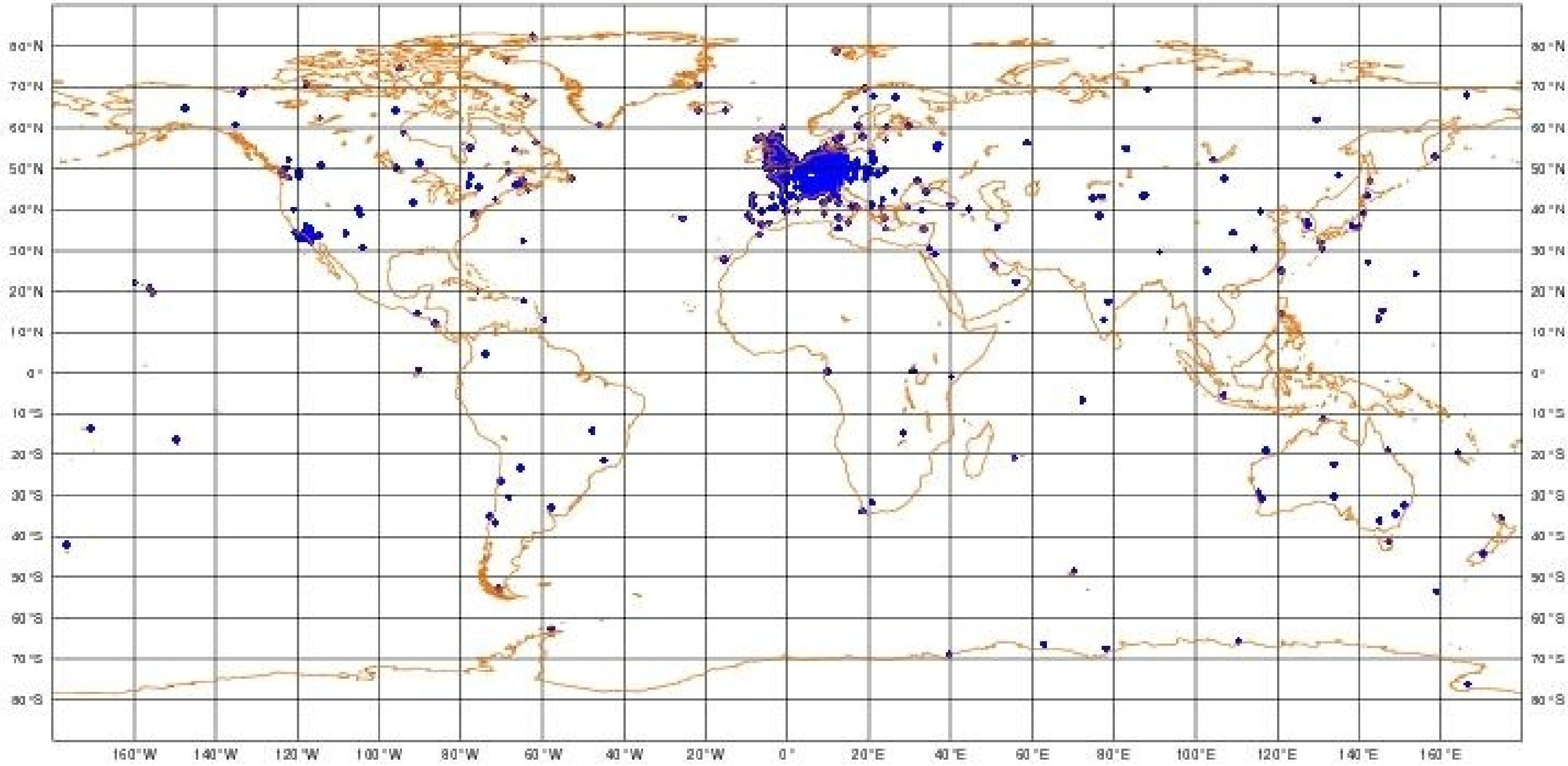
Data impact on numerical weather analyses: Degrees of freedom for signal

One day of observations fed into Météo-France's global model ARPEGE



The relative number of GPS radio occultation observations is small, but these data bear a strong weight, compared to other observation sources

One example of (so far, still largely) untapped resource for atmospheric studies: IGS ZTDs



Example of IGS ZTD data coverage for 20070404 12UTC

Could be used in:
- Reanalyses (requires consistent processing)
- Operational NWP (requires NRT availability)

Possible GGOS-enabled evolutions (1/2)

- For *all* geodetic delay data that are not yet used for atmospheric science studies:
  - Evaluate atmospheric information content
  - ➔ SP?
- For *all* geodetic delay data that are used for atmospheric sciences, but not available in NRT: (*e.g.* IGS ZTDs)
  - Assess whether NRT collection, processing & dissemination is feasible
  - ➔ A role for the Bureau of Networks and Communications?
- Promote deployment of geodetic-grade receivers for proven systems (radio occultation), by using opportunity concept
  - A role for the Satellite and Space Missions Bureau? [white paper: role#3 « advocate for advancement »]
  - ➔ Could go further: set-up alliances with manufacturers + a framework for easy data processing

Possible GGOS-enabled evolutions (2/2)

- From the outside, the atmospheric/ionospheric GNSS sounding communities remain clustered by missions/experiments or regions
  - Benefit to synchronize/standardize/compare practices for the processing of ground-based GPS and GPS radio occultation for atmospheric and ionospheric use and to give these communities a common voice
  - Currently a similar working group exists, recognized by WMO, NASA, NOAA, EUMETSAT, focusing on passive satellite sounders: the International TOVS Working Group (ITWG, a sub-group of the Radiation Commission of the International Association of Meteorology and Atmospheric Sciences, IAMAS)

  ➔ A role for a (new) GNSS Sounding Working Group (GS-WG) inside GGOS?

- Establish traceability of the retrievals down to raw measurements using standards ; necessary to prove that atmospheric GNSS measurements are irrefutable
  - GPS ZTD and GPS radio occultation measurements
  - What is the exact chain of processing to get these measurements, how sensible are they to changes in any component of the tracking network etc…

  ➔ Start by drafting a roadmap to establish SI-traceability: a role for …?

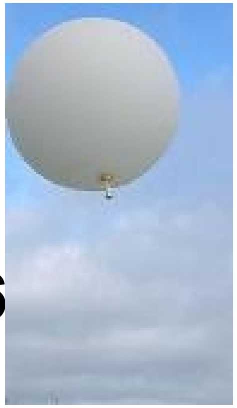
First set of conclusions

- A few GGOS components already provide valuable data to the atmospheric sciences
- Further evolutions possible thanks to GGOS
  ➔ Involve several entities within GGOS + SP
- Examples:
  – NRT collection
  – Set up a GNSS Sounding WG
  – Roadmap to SI-traceability

2. GGOS: a reference for geo-locating all Earth (atmospheric) observations

Example of Meteorology:

- *Realization* that <u>all</u> meteorological data would rely on a unique reference system for geolocation … came fairly recently
- Simple reason:
  - Any error in positioning is considered as an error in the total observation error budget
  - Each country was using its own geo-location system (national reference systems for ground weather stations, relative or local positioning systems for radiosondes…)
- Now: GPS sensors have spread to radiosondes…
- WMO has endorsed the use of WGS-84 and EGM-96 for positioning observing stations (June 2007)



Excerpt from a draft recommendation

WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR BASIC SYSTEMS,
EXTRAORDINARY SESSION
SEOUL, REPUBLIC OF KOREA, 9-16 NOV 2006

« Rec. 6.1/1(CBS-Ext.(6)) ADOPTION OF A WORLD GEODETIC SYSTEM AND A GLOBAL GEOID MODEL AS REFERENCES FOR POSITIONING THE OBSERVING STATION

THE COMMISSION FOR BASIC SYSTEMS,

Noting:

1. **The position of a weather station is given by longitude, latitude and altitude,**
2. **No standard reference system has been endorsed by the WMO to be used as the reference for both horizontal and vertical position of a station,**
3. **Both longitude and latitude require one universal standard positioning system as reference,**
4. **The International Meteorological Vocabulary (WMO-No. 182) defines the Mean Sea Level (MSL) as the average sea surface level for all stages of the tide over a 19-year period, usually determined from hourly heights observed above a fixed reference level, while the fixed reference level for MSL is yet to be identified,**

Considering that:

1. **The standard reference system the World Geodetic System 1984 (WGS 84) is applicable for the worldwide use by all applications used in meteorology,**
2. **Most regional and national systems refer to WGS 84,**
3. **The WGS 84 is endorsed by other international bodies, such as ICAO,**
4. **The Earth Geodetic Model - EGM-96 is applicable for all applications in meteorology,**

Recommends that:

1. **The World Geodetic System 1984 (WGS 84) be used as the primary reference for horizontal positioning;**
2. **The Earth Geodetic Model - EGM-96 be used as the fixed reference level for MSL determination;**
3. **The WMO Technical Regulations (WMO-No. 49) and the appropriate WMO Manuals and Guides are updated accordingly. »**

Excerpt from
WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR BASIC SYSTEMS
MANAGEMENT GROUP, SEVENTH SESSION
GENEVA, SWITZERLAND, 18-20 JUNE 2007

"EC-LIX approved draft Resolution 4/4 containing the adoption of a World Geodetic System (WGS-84) and a Global Geoid Model (EGM-96)as references for positioning the observing station. In the meantime the International Union of Geodesy and Geophysics informed WMO that a new global Geopotential model EGM07 has been completed and will be available at the end of 2007. It also pointed out that, for scientific studies requiring high accuracy (decimeter-type or better) the International Terrestrial Reference System (ITRS), defined by the International Earth Rotation and Reference Systems Service (IERS) may be a better solution for WMO scientific applications than WGS-84. This issue should be further studied by CBS."

EC-LIX = WMO Executive Council 59th session
CBS = Commission for Basic Systems

Second set of conclusions

- A communication channel exists between WMO and IUGG regarding the geodetic reference systems.
- To act as the primary contact point with WMO for these matters

➔ a role for which entity of the GGOS?

- Similar approach for unifying the geo-referencing of observations of
  - Ionosphere
  - Hydrosphere
  - Cryosphere
  - Biosphere

3. GGOS: a reference to be used in atmospheric modeling (gravity, geoid)

- Atmospheric models still use a very crude representation of
  - The reference geoid: a sphere
  - The gravity field: location independent *g*

- Simplifies greatly the modeling problem!

- But interdisciplinary research growth implies that an increasing number of researchers will combine datasets from different sources:
  - Oceanography, biology, animal tracks, epidemics, trading routes, …
  - Long-time series from atmospheric models (such as reanalyses)

- Even within the same field of meteorology, data that are referenced w.r.t. absolute coordinates cannot be compared directly with data that come out of a model in geocentric coordinates. Matching the two requires assuming that the model surface matches the real geoid…

Ideally…

- Earth system (atmospheric) models would use a geoid shape and gravity model provided by GGOS
- But… this requires quite some preliminary work on the atmospheric sciences' side, who do not see the value of added complications for the performance/accuracy of their simulation results

… for now, what seems reasonable:

- Atmospheric model (reanalyses) outputs could benefit from conversion tools ITRS ⇔ models' coordinates

Third set of conclusions

- There is still a wide gap between coordinates used by atmospheric models (inside modeling and output datasets) and ITRS coordinates
- GGOS could help bridge that gap by providing procedures to project outputs into ITRS coordinates
- Further down the road: envision a mechanism for feeding geoid shapes and gravity models when atmospheric modelers are ready to use these

Conclusions: GGOS roles in the other Earth (atmospheric) science:

GGOS-2020 -- and evolutions

1. Provide data to the atmospheric &ionospheric communities
   - Further: expand/increase the feed of NRT data and prove stability for climate studies

2. Set geodetic reference for all data collection and referencing. Already started with meteorology.
   - Further: use precedent/example for other disciplines

3. Bridge the (widening) gap between the poor representation of the geoid and gravity field in (atmospheric) modeling and the state-of-the-art geodetic models

Google map of Bertinoro, Italy