

The genesis of the ACE+ anti-rotating satellites concept



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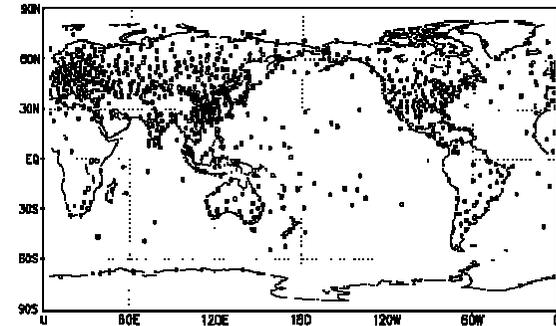
Introduction : interest of the WATS/ACE+ concepts

> Comprehension of scientific objectives

- Lack of atmospheric sounding data over oceans and other remote regions
 - Uncertainties in the initial state of global weather-prediction models limits their forecast capabilities.
 - Use of GPS limb soundings for temperature profiles retrieval

> Other missions heritage

- GPS/Met already flying, GRAS payload on MetOp
- ADM, ACE studies
- COSMIC mission



> WATS/ACE+ concept improvements with respect to these missions

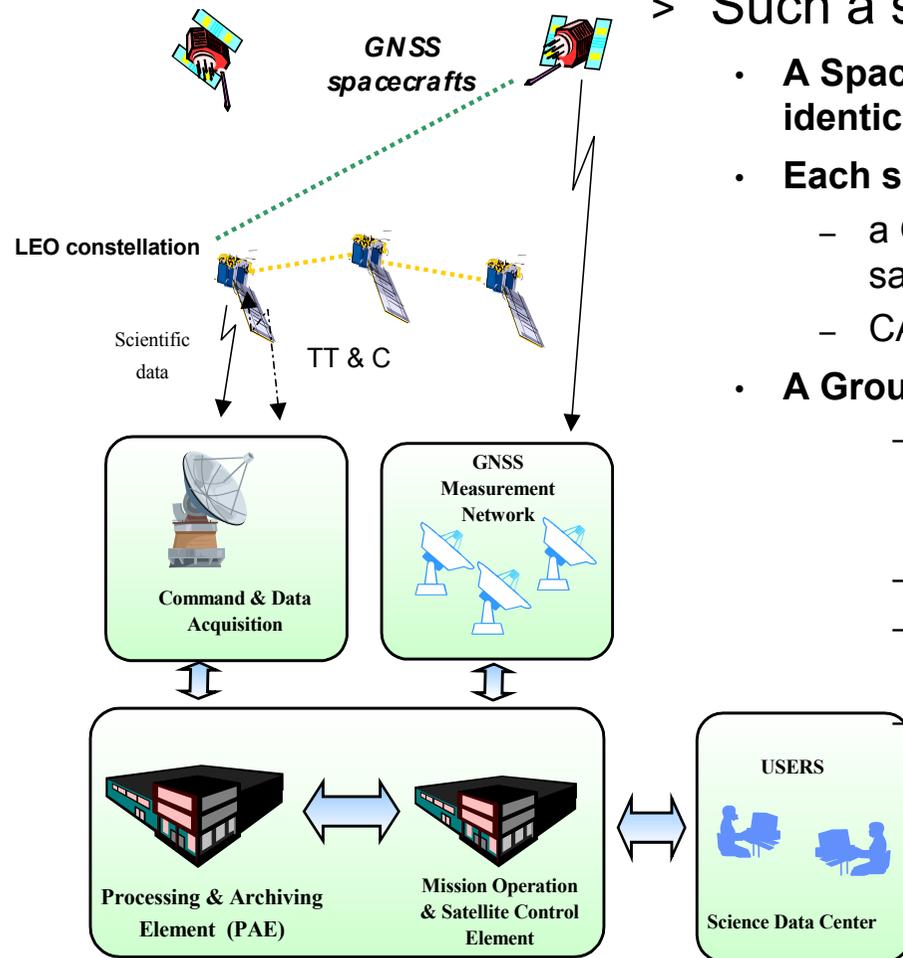
- Earth Global coverage
- LEO-LEO link for water vapour profile discrimination
- No need for a big ground segment

Impact of constellation design

- > Constellation design has a strong impact such system design
 - Overall system cost (number of satellites !)
 - System performances : occultation geometry
 - Number, horizontal/temporal distribution, “quality” of profiles
 - Payload architecture
 - antenna field-of-view, complexity of payload planning
 - Deployment strategy
 - Number of launchers (Cost and duration)

- > Dedicated studies have been conducted in Alcatel facilities
 - Occultation Mission Analysis Tool
 - Optimisation of constellation design
 - Performance evaluation
 - Continuously updated (modelling of useful occultations, characterisation of crosslink directions,...)

System Elements



> Such a system includes the following elements :

- **A Space Segment** composed of two sub-constellations of identical mini-satellites, spread over two orbit altitudes.
- **Each satellite carries 2 payloads,**
 - a GRAS receiver, which observes the occultation of GNSS satellites (GPS and Galileo)
 - CALL, a LEO-LEO occultation instrument (water vapour)
- **A Ground Segment**
 - A Command and Data Acquisition Element (CDAE), in charge of the TT&C links with the satellite and of the acquisition of the scientific data from the satellite.
 - A Ground network of GNSS reference receivers
 - A Mission Operations and Satellite Control Element (MSCE)
 - A Processing and Archiving Element (PAE), A Science Data Centre (SDC) (users)

Main system requirements

> Example of WATS system requirements

Number of LEO-LEO crosslink occultation events	> 1600 events per day (24 hours period), continuously over the mission lifetime.	} → Impact on constellation design
Geographic distribution	Geographical distribution of event locations per day (24 hours period) as homogeneously as possible, i.e., aiming at a uniform density of events per unit area over the globe.	
Temporal distribution	Local time (LT) distribution of event occurrence times per month (30 days period) as homogeneously as possible, i.e., aiming at a uniform density of events per unit local time.	
Minimal Vertical Atmospheric Domain to be covered by a LEO-LEO event	1 km – 20 km (performance at the lowest level – PBL – shall not drive the design)	} → Occultation Quality
Minimal Vertical Atmospheric Domain to be covered by a GNSS-LEO event	1 km – 90 km	
Maximal Horizontal Atmospheric Domain to be crossed during vertical crossing of the “Minimal Vertical Atmospheric Domain”	500 km (considered to be the point closest to the geoid during the occultation event)	→ Impact on G/S and data down-link
Timeliness	About 30% of the data should be available in near real time. This data should be made available to NWP centers for assimilation, whereas all data should be made available for climate research.	→ Spare strategy not needed
Baseline Mission Lifetime	7 years	
Risk of “graceful degradation” of the constellation towards the end of the lifetime	Acceptable (Design goal should be the full mission over a lifetime of 5 years)	→

Constellation concepts

- > How were selected the constellation concepts ?
 - Occultation geometry is the core of the problem
 - Trade-off between **intra-plane occultations** and **inter-plane occultations**
- > The use of Walker constellations is classical
 - For constellation design aiming at optimising figures of merit such as N-fold coverage or DOP (Dilution of Precision, used for navigation constellations such as GPS or Galileo).
 - An analogy with the coverage requirements of the mission led us as a first option to investigate the Walker option.
- > Proposition of two options
 - Option 1 : inclined Walker patterns
 - Option 2 : polar orbits with anti-rotating satellites

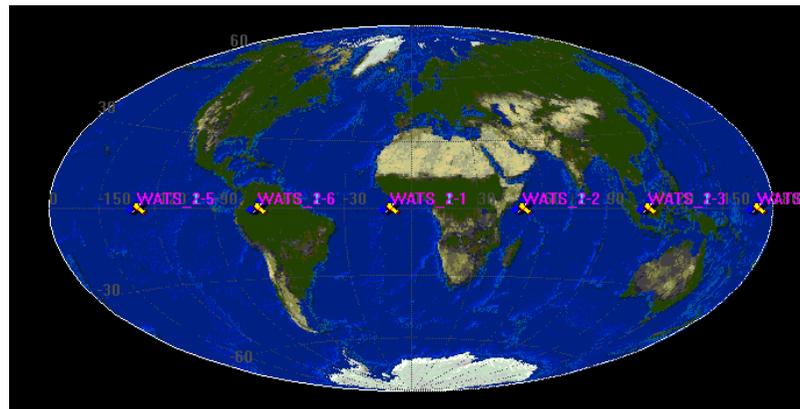
The Walker constellation option : description

> Preliminary optimisation was as following

<i>WALKER CONCEPT</i>	<i>NUMBER</i>	<i>PLANES</i>	<i>ALTITUDE</i>	<i>INCLINATION</i>	<i>COMMENT</i>
SUB-CONSTELLATION A	6 SATELLITES	6 PLANES	650 KM	72°	WALKER 6/6/0
SUB-CONSTELLATION B	6 SATELLITES	6 PLANES	850 KM	70°	WALKER 6/6/0

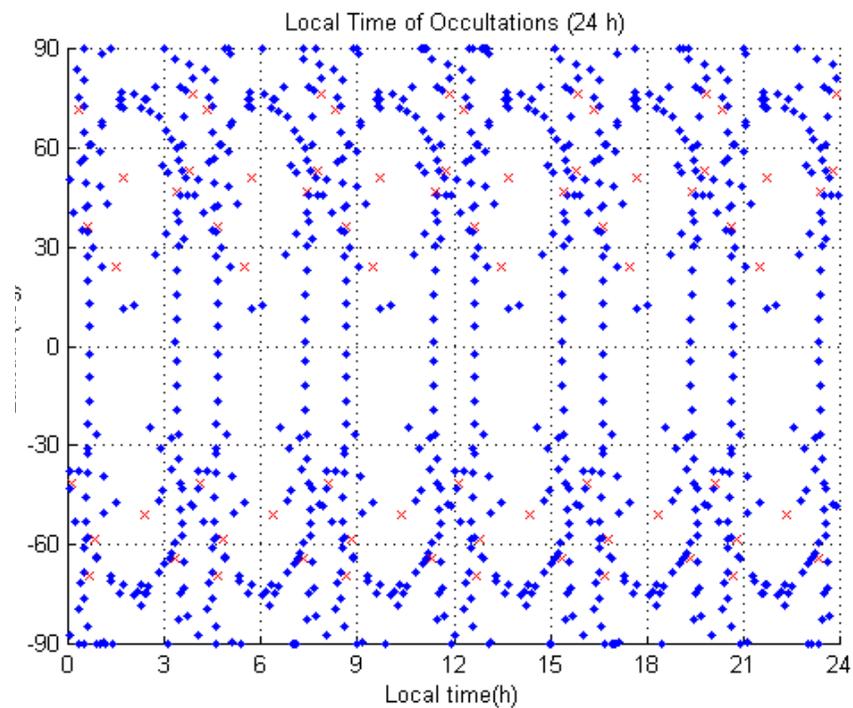
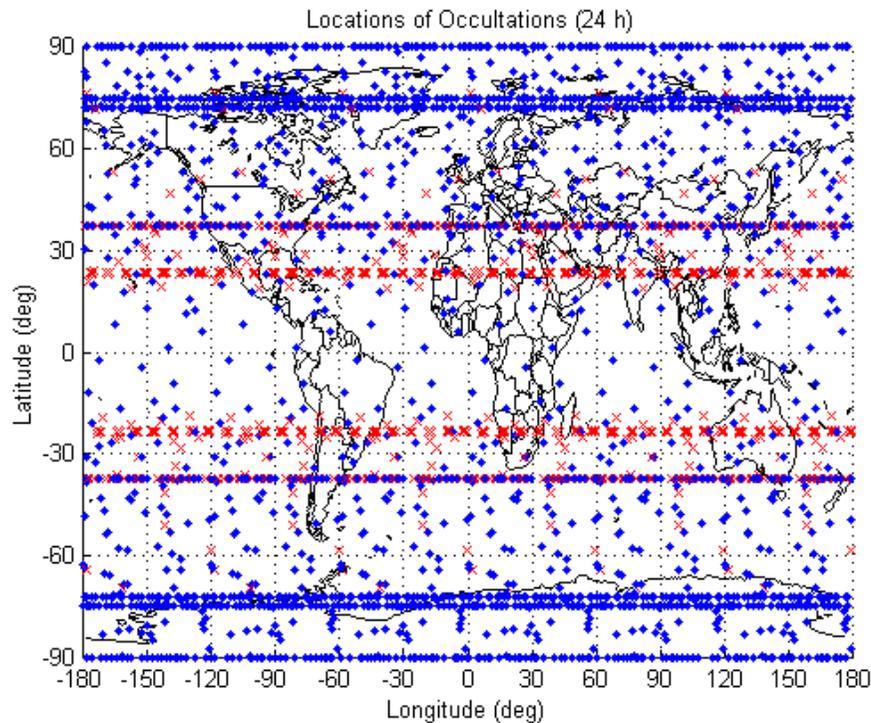
> Walker constellation design

- T/P/F : Number of Sat per plane / Number of plane / Interplane Spacing
- Inclination was adapted to J2 induced drift



The Walker constellation option : performances (1)

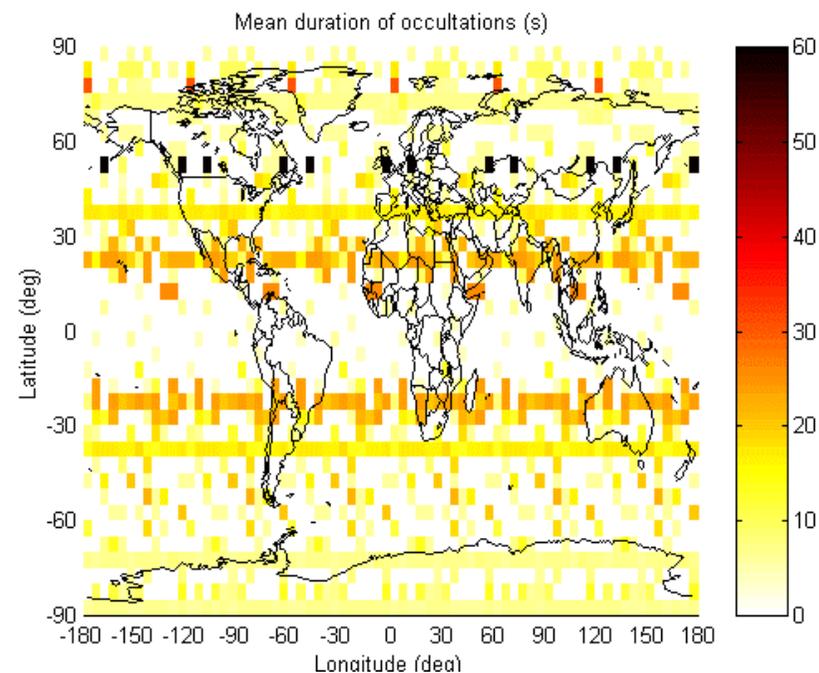
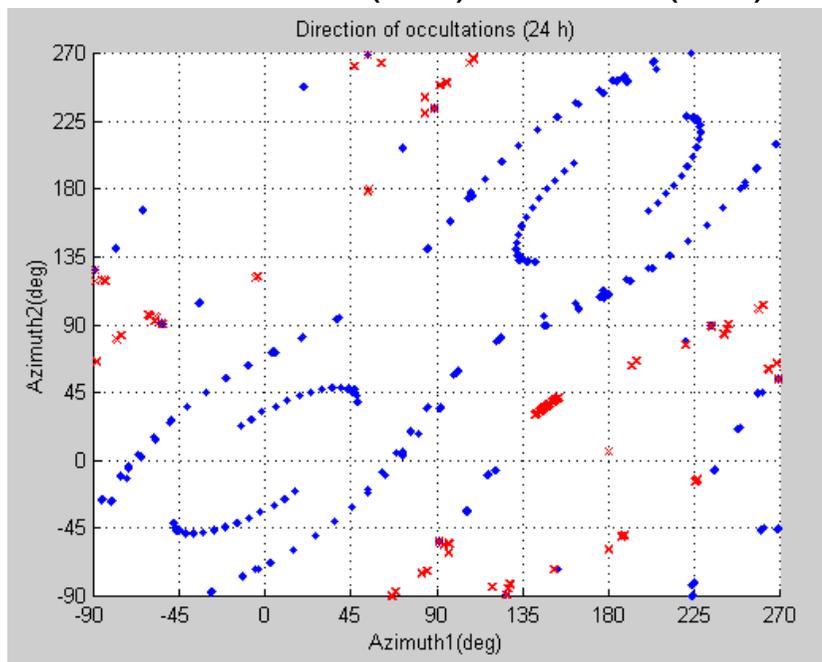
- > Number of occultations :
 - 2889 per day (2097 of « good quality » < 100km)



- > Constellation inclination is highly noticeable

The Walker constellation option : performances (2)

- > Geometry of occultations is poor
 - Occultation spread over the directions
 - Total number of occultations decreases sharply with antenna aperture.
 - 2829 (90°) → 1875 (80°) → 204 (45°)



The Walker constellation option : Constraints (1)

- > Consequence of the relative geometry of the occultations
- > Three options can therefore be considered :

- Manoeuvring spacecraft

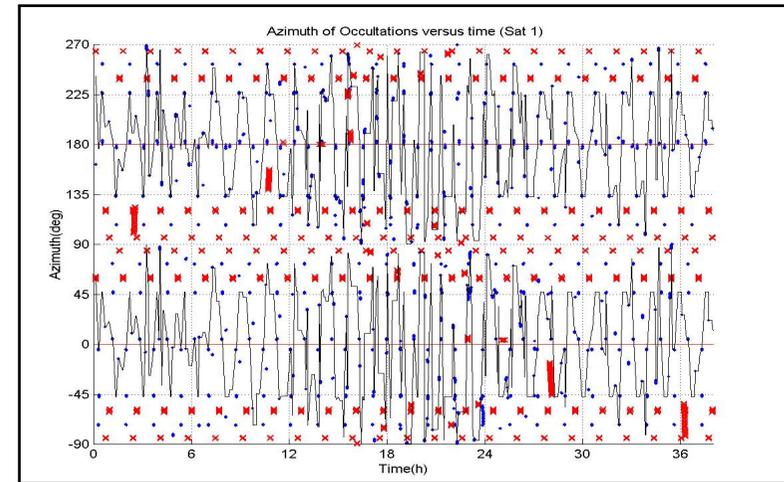
- the limitation of the spacecraft manoeuvring capabilities limits as a consequence the number of occultations
- the manoeuvre planning is relatively complex
- The spacecraft stability requirements (derived from the LEO-LEO link gain constraints) are difficult to reach.

- Steerable antenna (mechanical)

- Preliminary iterations of mechanical constraints and gain stability requirements discard rapidly this option.

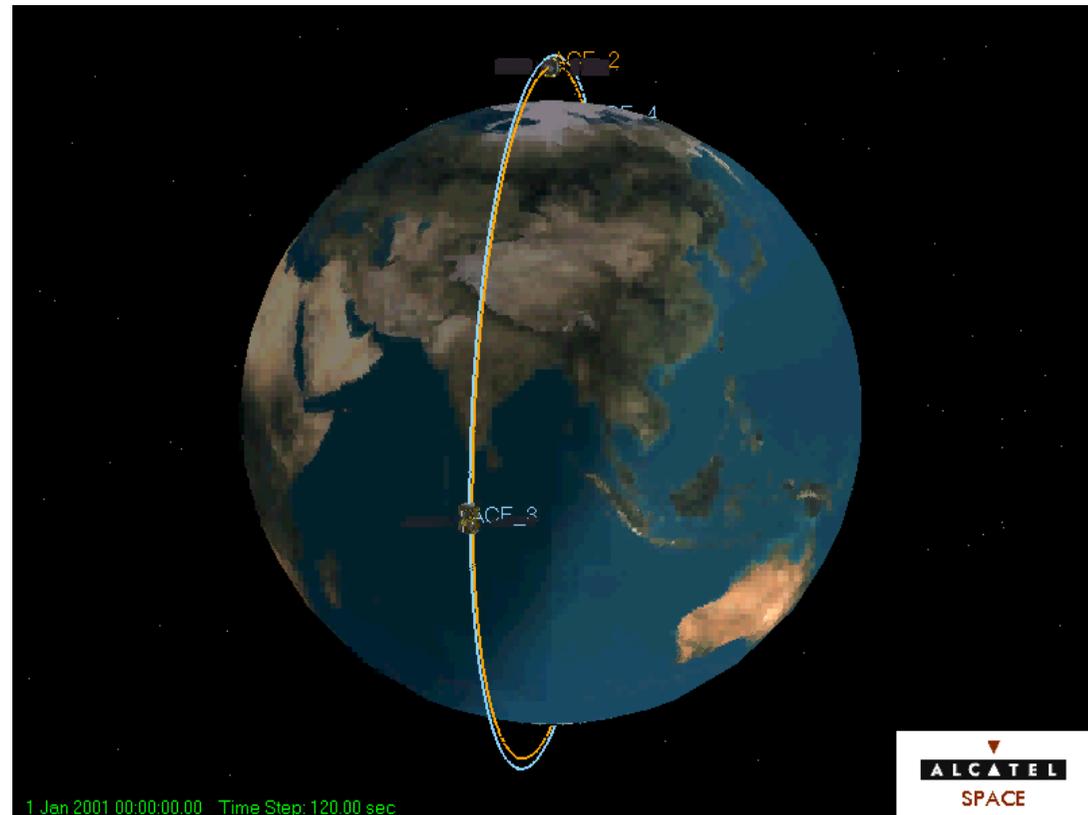
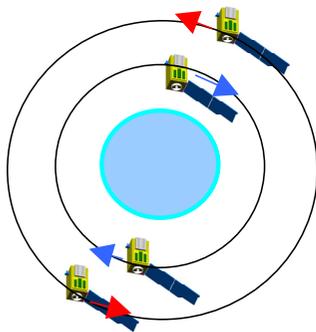
- Steerable antenna (electronically)

- An electronic antenna is not able to go up to the required $\pm 90^\circ$ of angle to track the side occultations. As a result of this, a reasonable steering capability ($\pm 30^\circ$) lead to a severe drop in the number of tracked measurements.



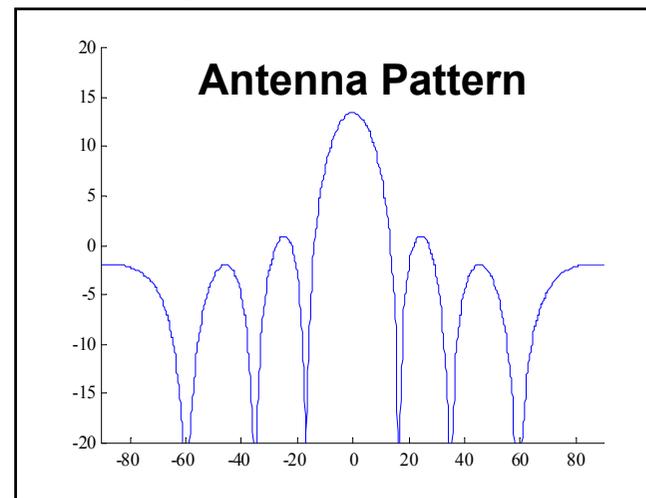
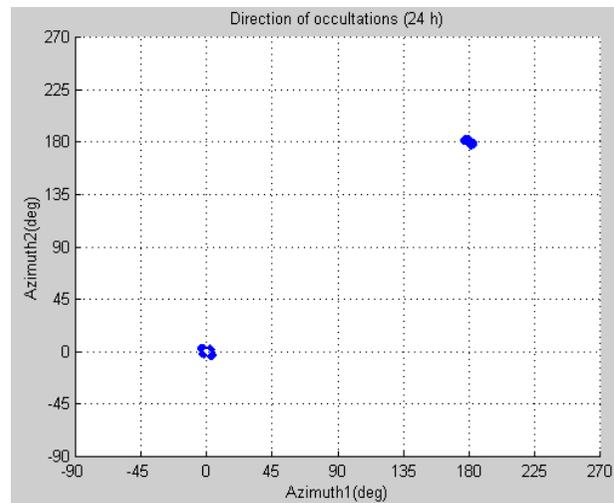
The Anti-rotating concept : Description

- > The second type of concept considers orbits shared by satellites rotating in opposite senses :
 - 6 satellites at 650 km inclined at 90° ; 6 satellites at 850 km at 90° .
- > This constellation concept is **unstable for non-polar orbits** (would lead to a very high need of station-keeping manoeuvres)
 - For a 70° inclination the drift is about $\pm 2.2^\circ/\text{day}$. For polar orbits, the node drift is null and the orbital configuration is stable.



The Anti-rotating concept : Key advantages

- > Antenna : No need of large instrument aperture
 - The key advantage of the polar concept lies in the reduction of the antenna field of view requirements (here one “plane” configuration)



- > Other Advantages
 - Gain stability and Occultation quality
 - Payload planning is elementary
 - No manoeuvres

The Anti-rotating concept : performances (1)

- > For anti-rotating polar concepts, (with a narrow instrument aperture along velocity and anti-velocity directions) the following equation is an approximation of the relation existing between the number of LEO-LEO crosslinks, the number of satellites and the number of polar planes :

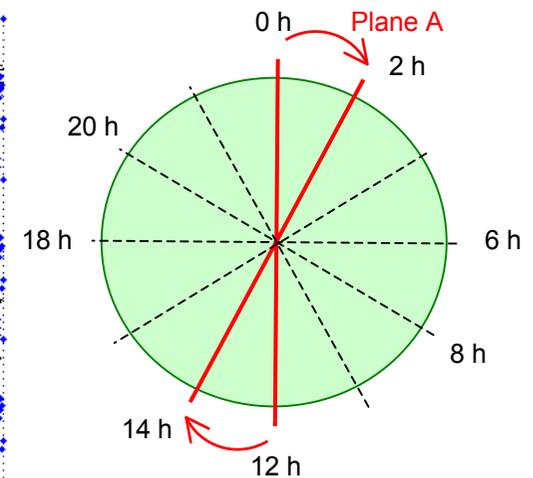
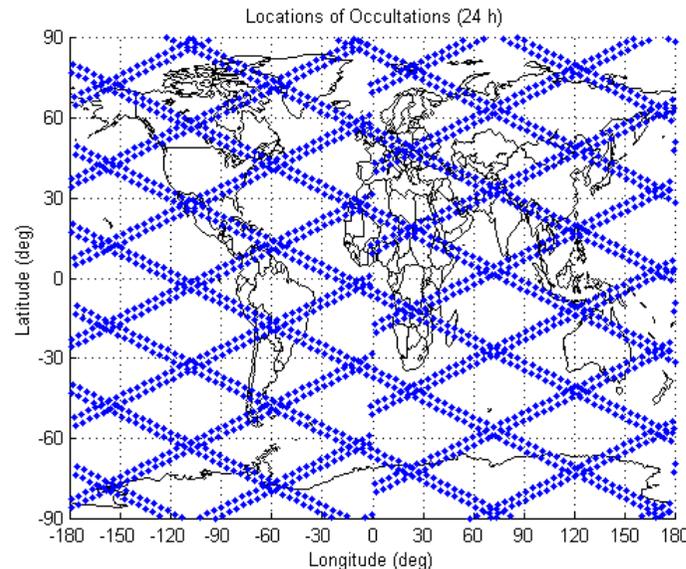
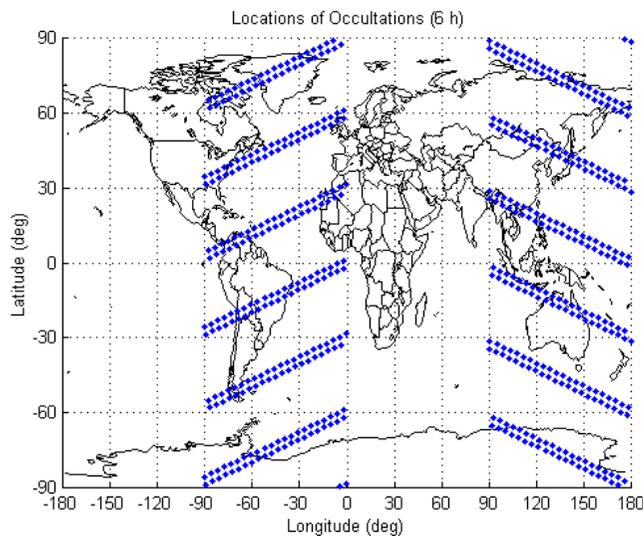
$$N_{occultation} \cong \frac{24}{T_{approx}} 4k^2 P$$

$N_{occultation}$ = Approximate number of occultations per 24 h on velocity and anti-velocity directions
 T_{approx} = Mean value of orbital periods (in hour) at 650 and 850 km (≈ 1.67 hours)
 k = Number of satellites per plane and per altitude (e.g. 6, 3, 2, or 1 with 12 satellites)
 P = Number of polar planes (e.g. 1, 2, 3, or 6 with 12 satellites)

Number of satellites per altitude and per plane	Number of polar planes	Number of satellites	Number of occultations per day
2	1	4	230
3	1	6	518
4	1	8	922
5	1	10	1440
2	2	8	461
1	3	6	173
6	1	12	2074
3	2	12	1037
2	3	12	691
1	6	12	346

The Anti-rotating concept : performances (2)

> Repartition of LEO-LEO occultations (1 polar plane)



Evolution of the local time of
1 polar orbital plane for 1 month

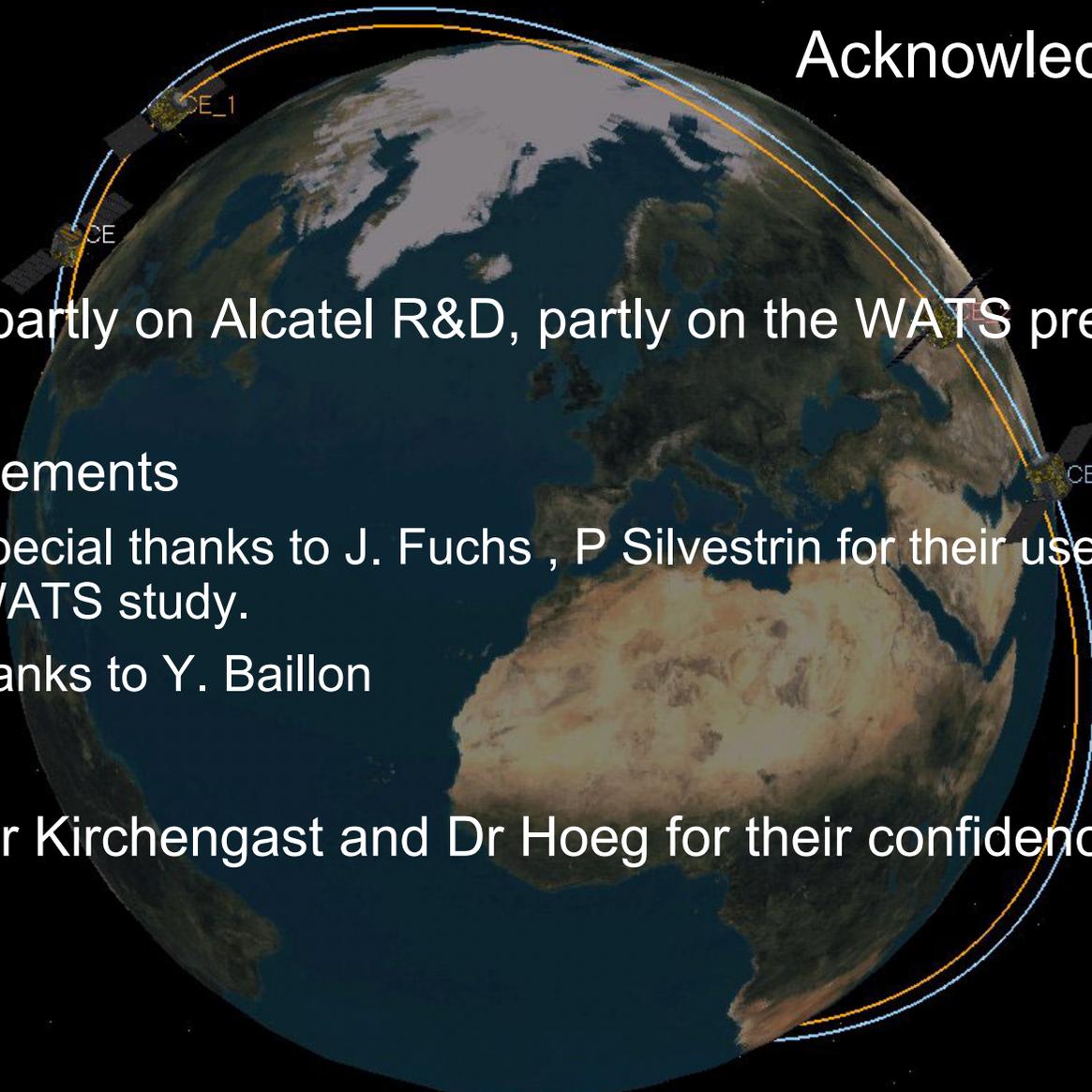
- > Polar constellation offer a homogeneous coverage of the world. This homogeneity increases with the number of polar planes
- > Local time sampling is acceptable if considered over long periods of time

Conclusion

- > During the WATS pre-phase A, two constellation concepts have been proposed by Alcatel
 - Walker type constellation
 - Anti-rotating satellites concept
- > The anti-rotating satellite concept is a key point to the system feasibility by reducing the constraints on main parts of the system
 - Antenna
 - Non manoeuvring satellite
 - No simplified payload planning
- > Incoming ESA ACE+ mission will take benefit of Alcatel WATS experience and heritage
- > Alcatel Space is firmly committed to ACE+ success



Acknowledgements



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- > Acknowledgements
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