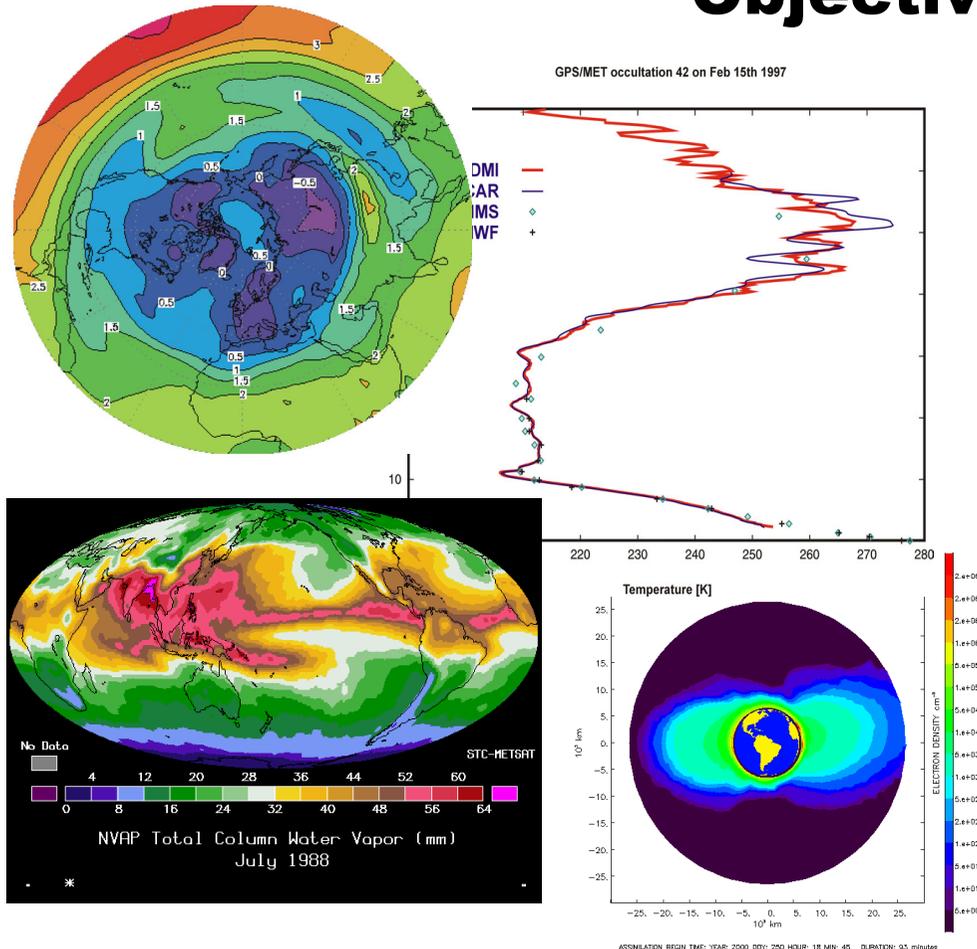


# ACE+

## An Atmosphere and Climate Explorer based on GPS, GALILEO, and LEO-LEO Occultation

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**Gottfried Kirchengast (IGAM/UG)**

# Objectives



## Climate

- Monitoring global long-term variations in the climate and the forcings of the atmosphere system giving rise to trends

## Atmosphere

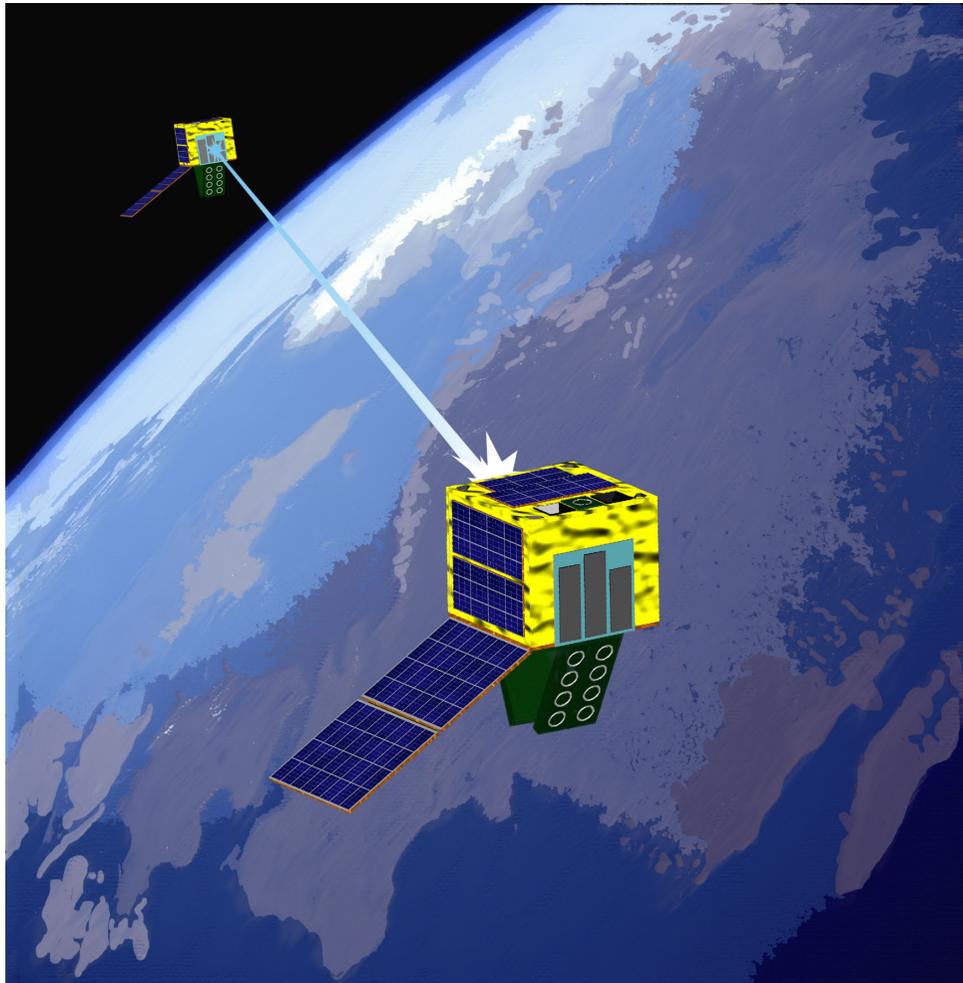
- Observe and analyze globally the physical condition and state of the atmosphere of the Earth to improve predictions of future state

## Space Weather

- Monitoring and modeling of ionosphere and plasmasphere electron density structures

## Scientific Objectives

- **Major goal:**
  - ♦ To monitor and describe variations and changes in the global atmospheric temperature and water vapour distribution in order to assess climate changes caused by mass field changes and atmosphere dynamics.
  
- **Main objectives:**
  - ♦ To establish highly accurate ( $< 0.003$  g/kg and  $< 3$  % in specific humidity) and vertically resolved ( $< 1$  km) global climatology of water vapour in the troposphere;
  - ♦ To establish a highly accurate ( $< 0.2$  K) and vertically resolved ( $\sim 1$  km) global climatology of temperature in the troposphere and the stratosphere;
  - ♦ To perform research on climate variability and climate change together with research in improved atmospheric models as well as advancements in NWP;
  - ♦ To study troposphere structures in polar and equatorial regions;
  - ♦ To support analysis and validation of data from other space missions;
  - ♦ To demonstrate a new and novel active atmospheric sounding technique with the CALL instrument;
  - ♦ To enhance the European observational capability for improved contribution to the international GCOS initiative.
  
- **Advances in atmosphere physics and climate change processes:**
  - ♦ Global climate warming and increased averaged atmospheric water vapour levels;
  - ♦ Tropical heat and mass exchange with extra-tropical regions;
  - ♦ Transport across subtropical mixing barriers, relevant for information on the lifetime of greenhouse gases;
  - ♦ Stratospheric winds and temperatures and atmospheric wave phenomena;
  - ♦ Polar front dynamics and mass exchange together with tropospheric water vapour feedback on climate stability;
  - ♦ High latitude tropospheric-stratospheric exchange processes related to polar vortex conditions;
  - ♦ Climatology of Rossby waves and atmospheric internal waves.

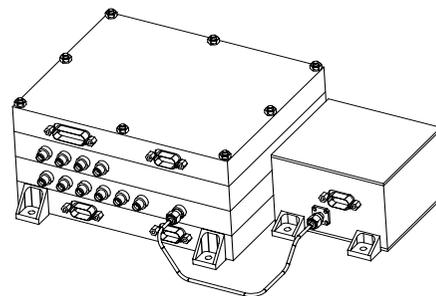
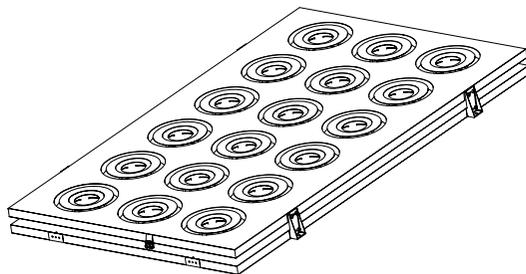
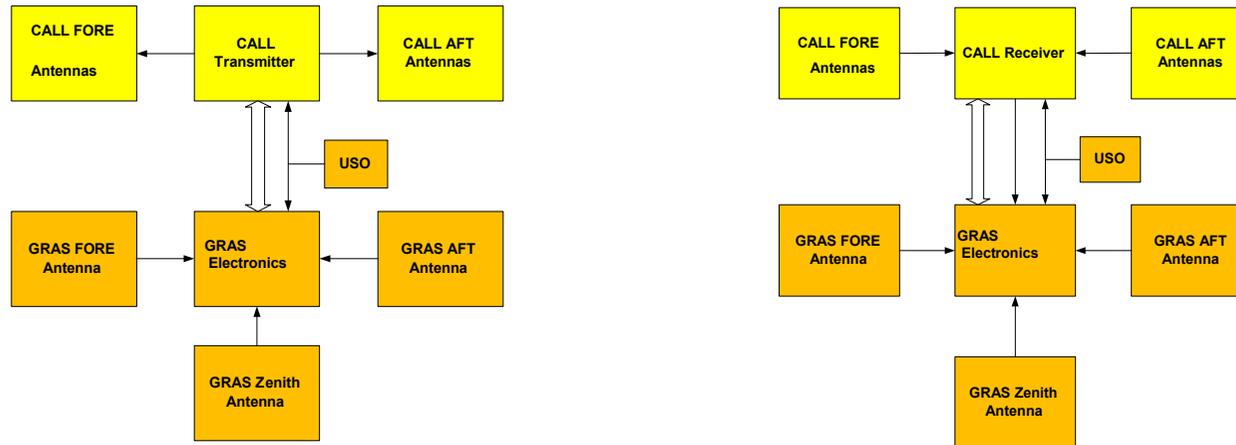


## Satellite Constellation

- **4 micro-satellites**
  - Mass: ~130 kg
  - Power: ~80 W
- **Stable two-plane constellation in 90 degrees inclination**
  - In each plane, counter-rotating orbits with 2 satellites - for optimizing quality of measurements
- **Two altitudes**
  - Heights 650 km and 850 km – to optimize spatial distribution of occultations
- **Orbital local time drift**
  - To optimize the temporal and local time distribution of occultations
- **Instruments**
  - L-band GPS/GALILEO precision receiver
  - X/K-band LEO-LEO precision transmitter and receiver (2 of each)

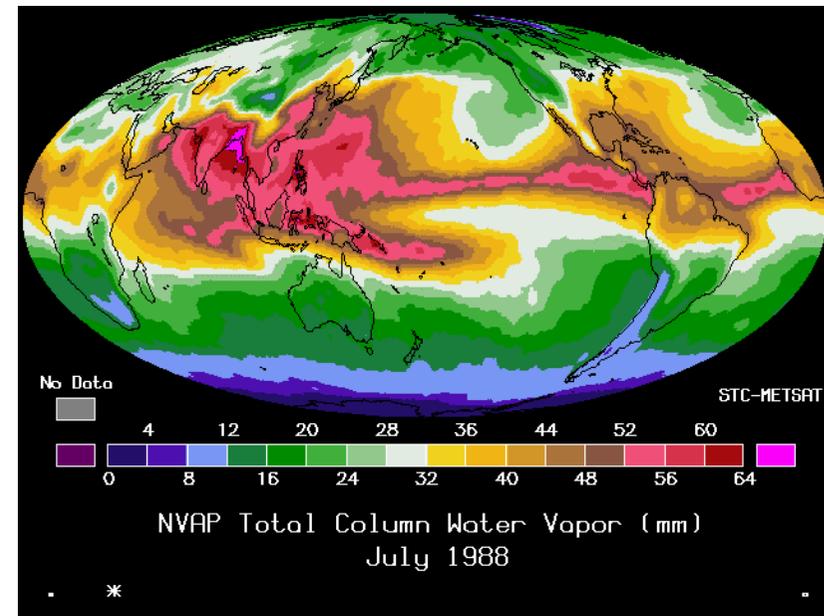
## ESA GNSS Atmosphere Profiling Missions

Year	EXPLORER Missions	
	CORE	OPPORTUNITY
1996	<b>Atmospheric Profiling Mission</b> (One of 9 pre-selected proposals)	
1998		<b>ACE</b> ( <u>A</u> tmosphere <u>C</u> limate <u>E</u> xperiment) (Selected 3rd out of 27 proposals - Total: 33)
2000	<b>WATS</b> ( <u>W</u> ater Vapour in the <u>T</u> roposphere and <u>S</u> tratosphere) (One of 5 pre-selected proposals - Total: 10)	
2001		<b>ACE+</b> ( <u>A</u> tmosphere <u>C</u> limate <u>E</u> xplorer) (Selected 1st out of 25 proposals - Total: 28)

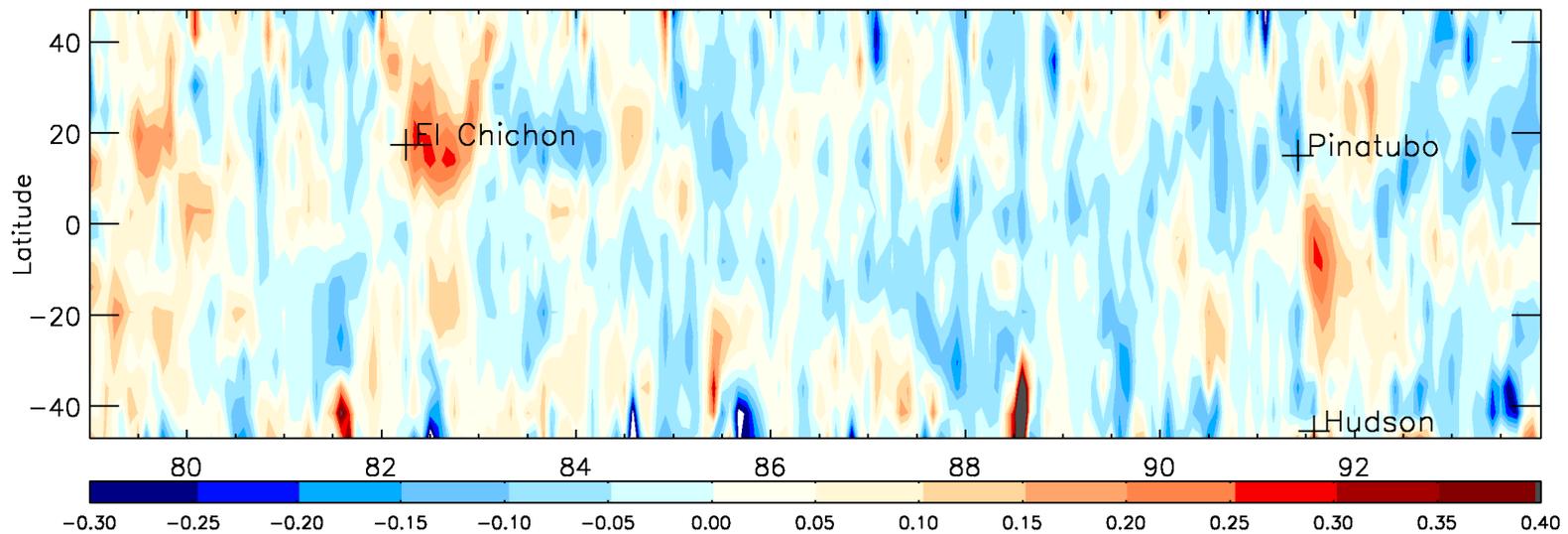


## Why are measurements of atmospheric water vapor important?

- Indicator of climate change
- Strongest greenhouse gas
- Climate positive/negative feedback
- Energy reservoir
- Impact/feedback on global wind system changes and general atmosphere dynamics
- Hydrologic cycle
- Highly variable (time and space)



# Global Temperature Deviations



## Forcing residuals in atmospheric models

$$\left. \frac{\partial F}{\partial t} \right|_O = \left. \frac{\partial F}{\partial t} \right|_M + R$$

Estimation of the residual ( $R$ ) requires availability of high quality observed data.

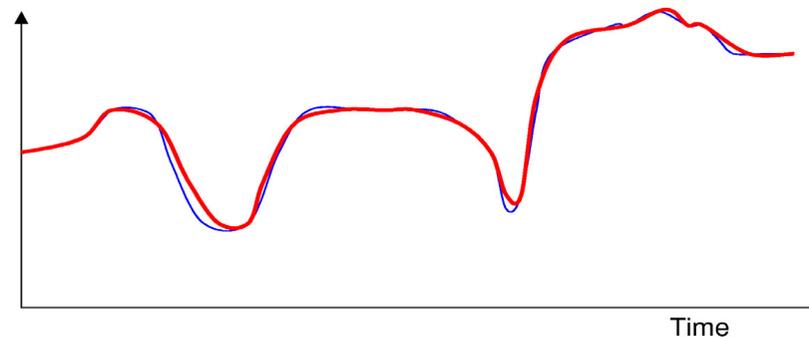
Forcing residuals can be used to:

- identify tendency errors in the differential equations of atmospheric models
- detect temporal variations in external forcing of the atmosphere.

## Weak nudging towards the re-analyses

Data assimilation via nudging:

$$\left. \frac{\partial \Psi}{\partial t} \right| = \left. \frac{\partial \Psi}{\partial t} \right|^* + \frac{\Psi^{obs} - \Psi^{MOD}}{\tau}$$



Discretization in time (assimilation in spectral space):

$$\Psi_{n,m}(t + \Delta t) = \Psi_{n,m}^*(t + \Delta t) + 2\Delta t \frac{(\Psi_{n,m}^{ERA}(t + \Delta t) - \Psi_{n,m}(t + \Delta t))}{\tau}$$

Forcing residual is approximated by the last fraction:

$$R_{n,m}(t + \Delta t) \approx \frac{(\Psi_{n,m}^{ERA}(t + \Delta t) - \Psi_{n,m}(t + \Delta t))}{\tau}$$

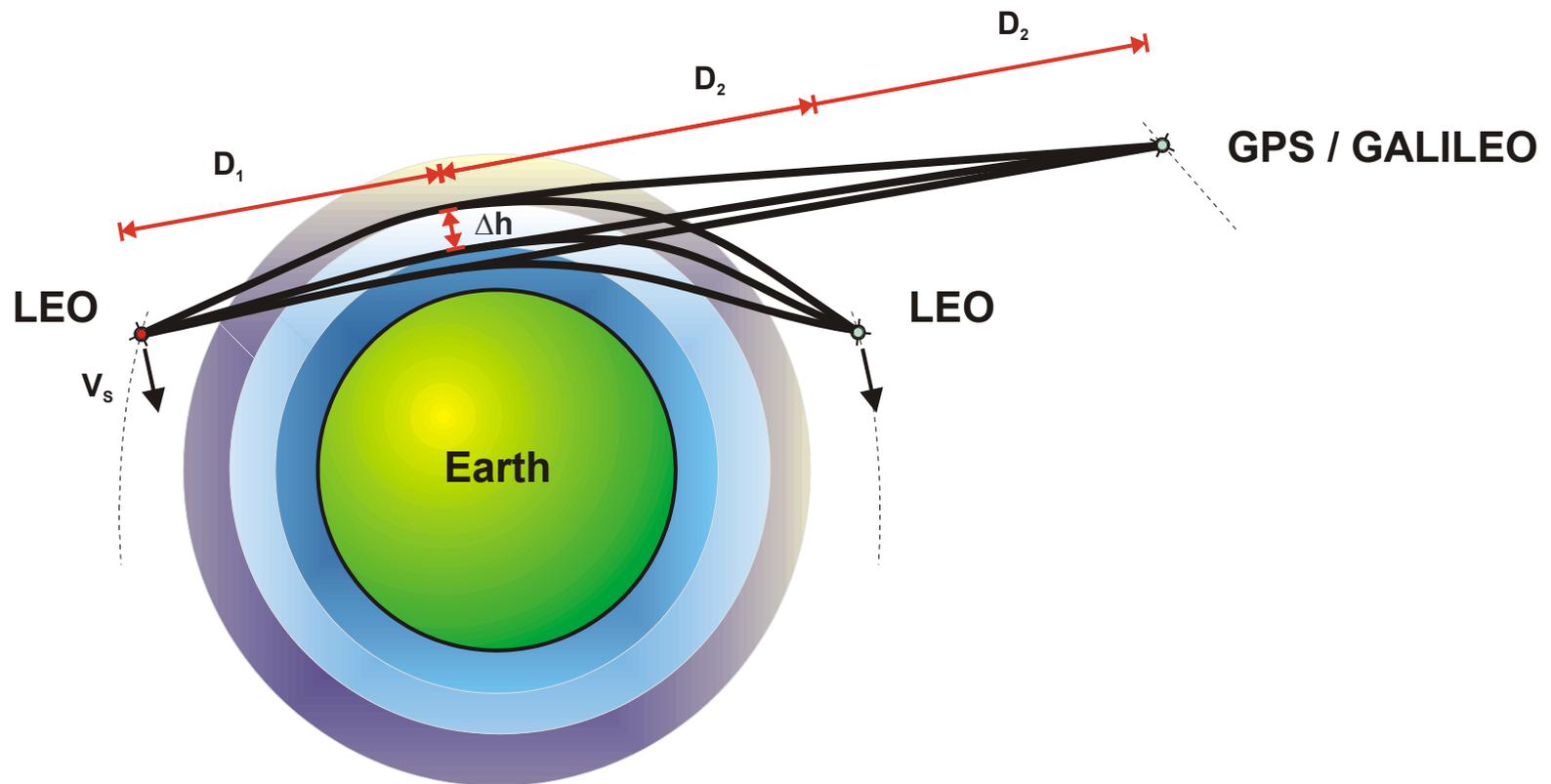
## WMO Requirements

**Main indicators:** **Wind,  
Temperature, Pressure,  
Water Vapor**

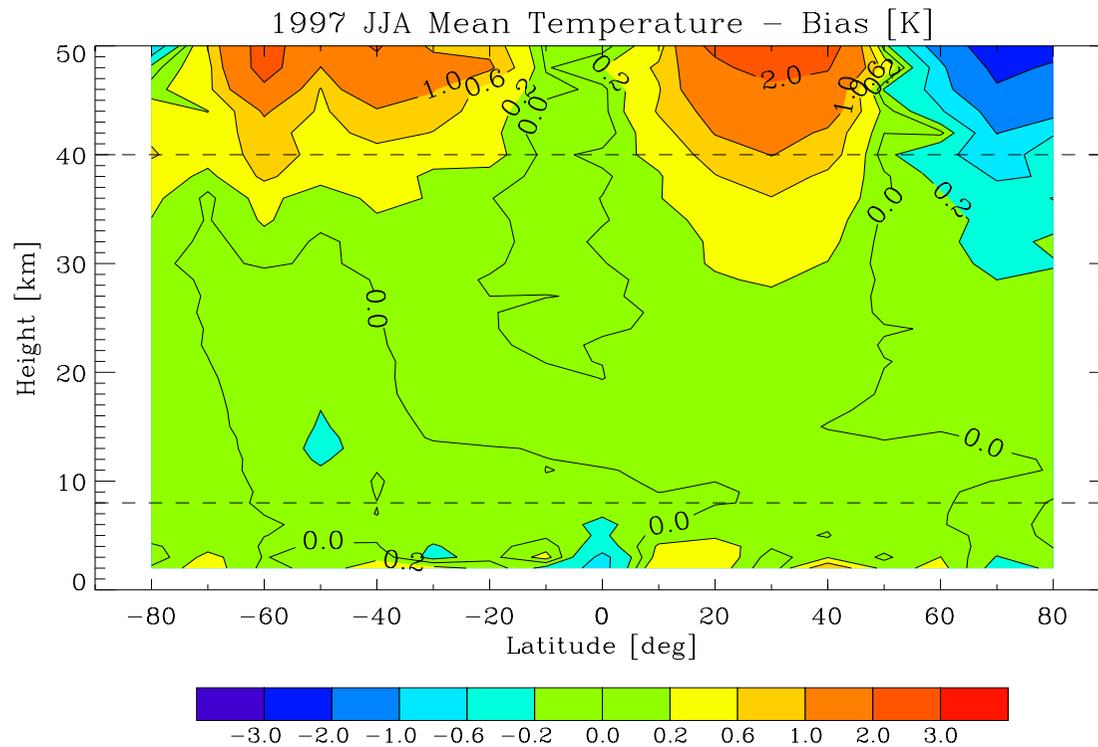
◆ **Requirements for improved weather forecasting**

- *Temperature:* < 0.3 % [180 – 335 K]
- *Pressure:* < 0.3 % [0.5 – 1100 hPa]
- *Water vapor:* < 20 % [1 – 45 hPa]
- *Coverage:* global [data separation < 500 km]

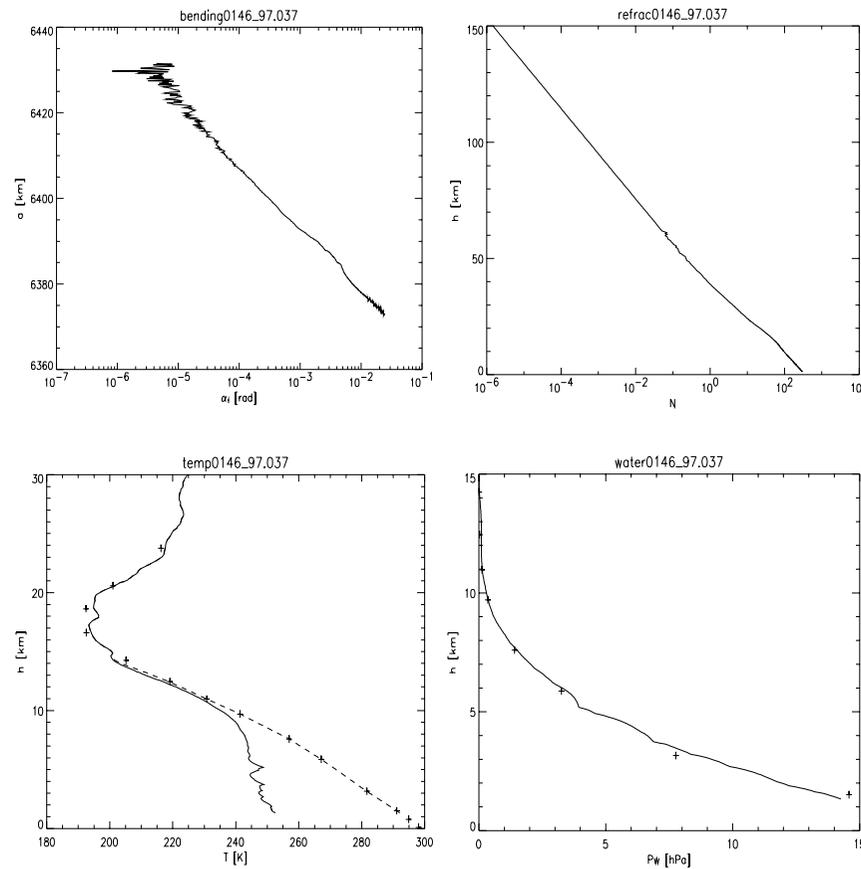
# The ACE+ Experiments



# GRAS Temperature Retrieval



# Processing Steps for Water Vapor Retrievals

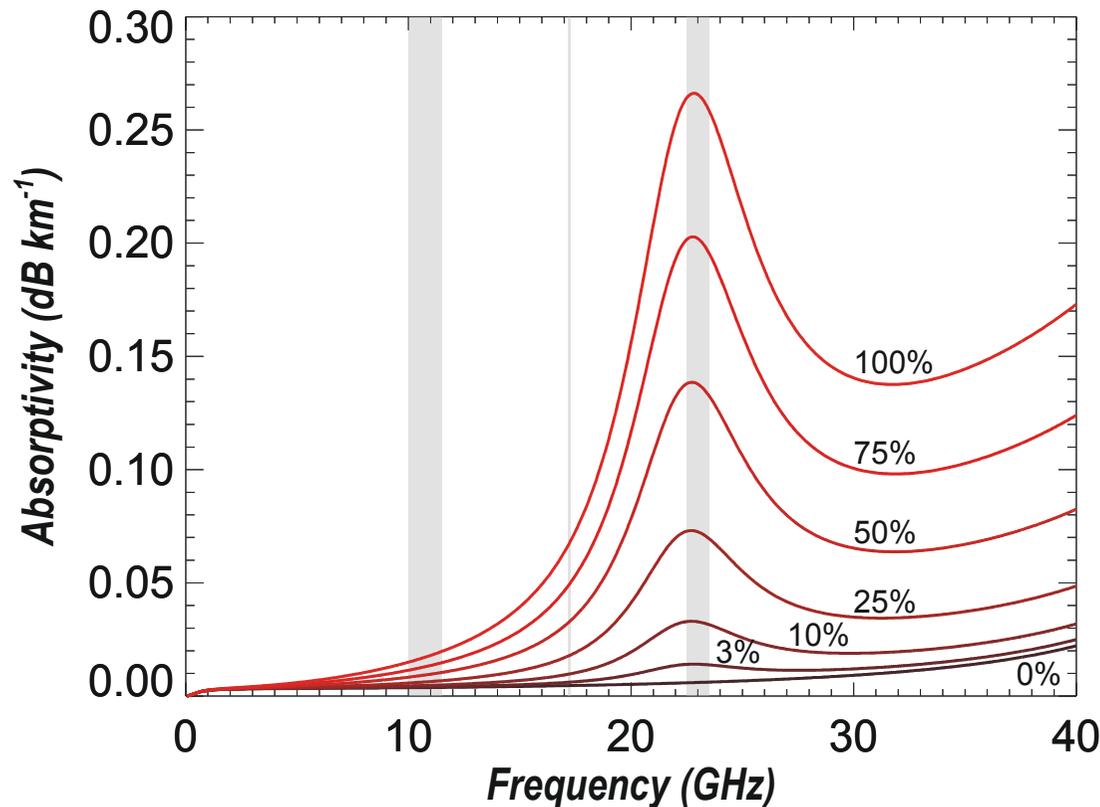


# GRAS Requirements

Parameter		Temperature	Humidity
Horizontal domain		Global	Global
Horizontal sampling		1.0°x1.0° - 2.5°x2.5°	1.0°x1.0° - 2.5°x2.5°
Vertical domain		Surface - 1 hPa (0 - 50 km)	Surface - 300 hPa (0 - 10 km)
Vertical Resolution	Troposphere	0.5 km	0.5 km
	Stratosphere	1 km	–
Time domain		> 5 years	> 5 years
Time resolution		1 - 10 years	1 - 10 years
Long-term stability		< 0.1 K/decade	< 2% RH/decade
Number of profiles per grid box per month		> 40	> 40
Accuracy	Troposphere	< 1 K	< 10%
	Stratosphere	< 1 K	–
Timeliness (NWP)		3 hrs	3 hrs
Timeliness (Climate)		30–60 days	30–60 days

# Absorption of signals at X/K-band frequencies

## Water Vapor Absorption



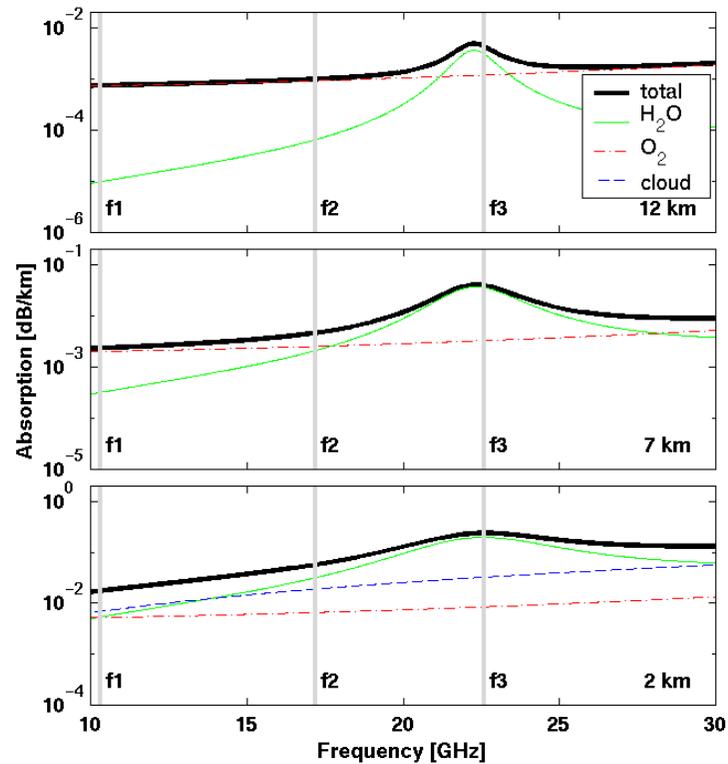
Permitted frequencies:

9.5- 9.8 GHz

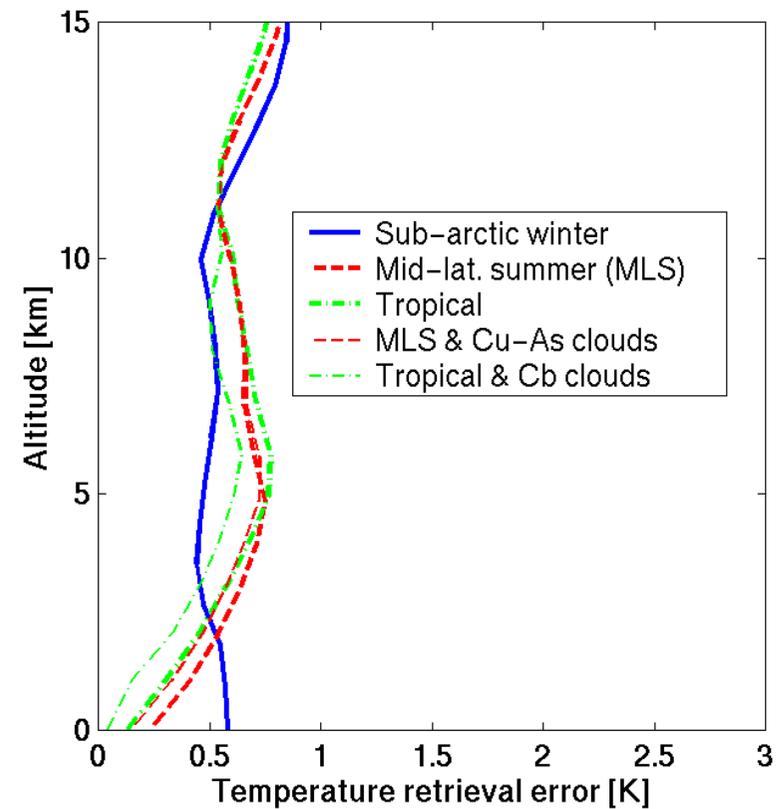
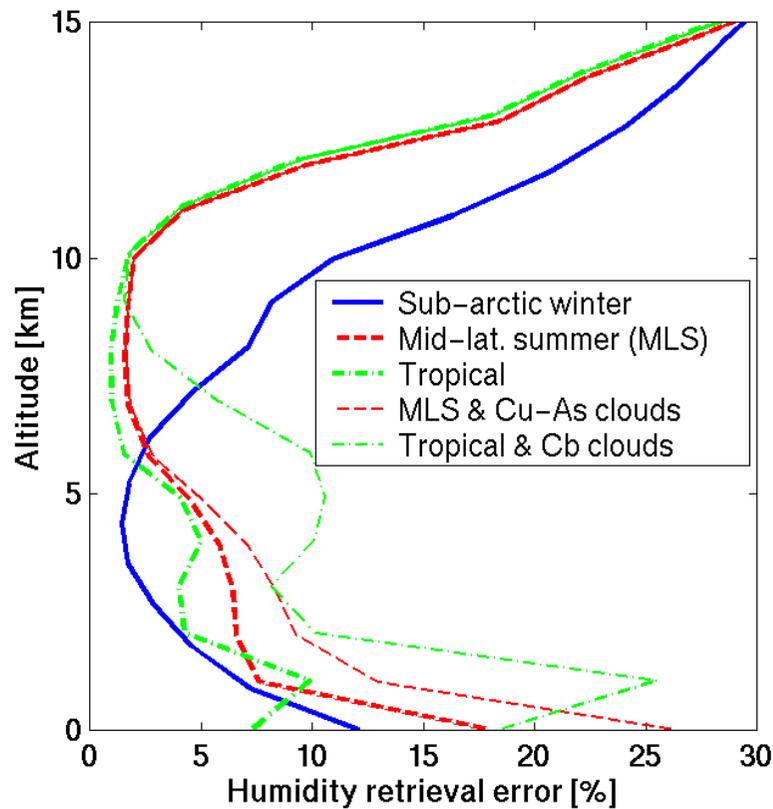
17.2-17.3 GHz

22.5-23.5 GHz

# Absorption properties



# CALL Temperature and Humidity Retrieval



# CALL

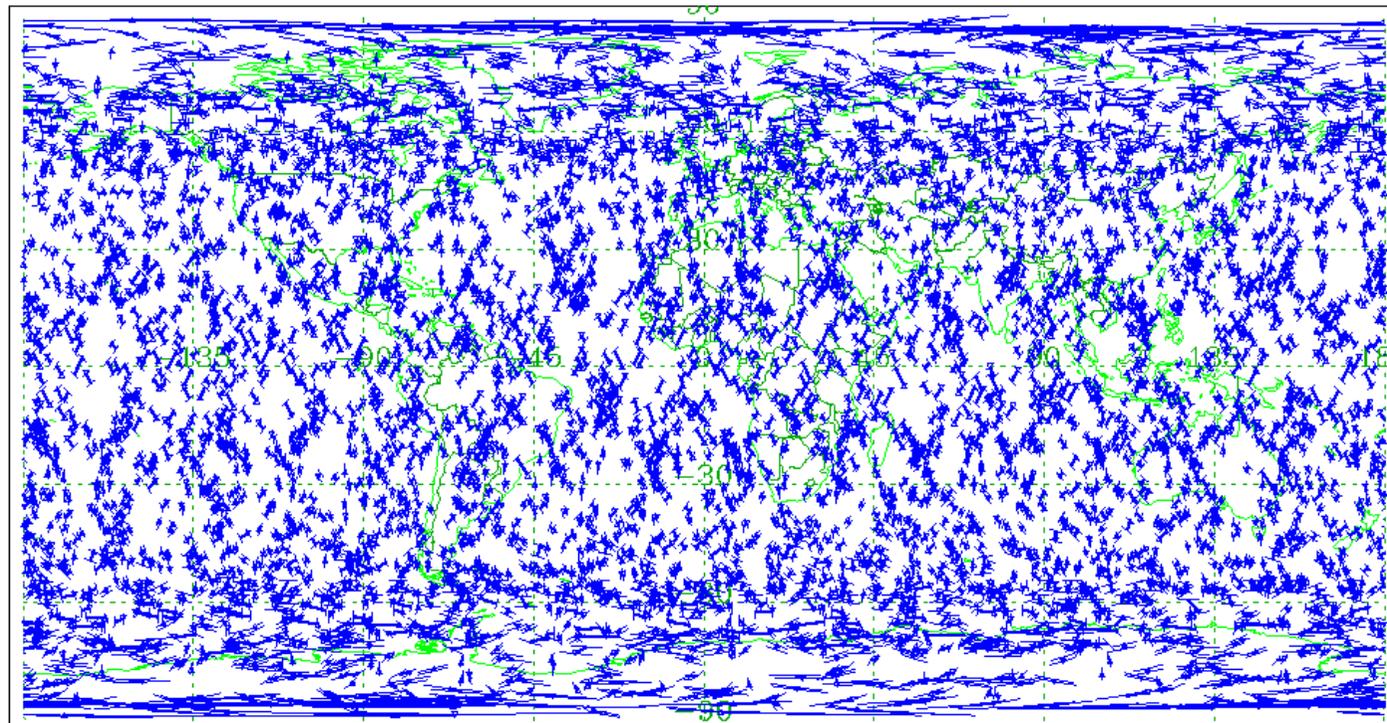
## Temperature and Humidity

## Requirements

Parameter		Specific Humidity	Temperature
Horizontal Domain		Global	Global
Horizontal Sampling		100–500 km	100–500 km
Vertical Domain		Surface to 10 hPa	Surface to 100 hPa
Vertical Sampling	LT	0.4–2 km	0.3–3 km
	HT	0.5–2 km	1–3 km
	LS	–	1–3 km
	HS	–	5–10 km
Time Sampling		3–24 hrs	3–24 hrs
RMS Accuracy	LT	0.25–1 g/kg	0.5–3 K
	HT	0.025–0.1 g/kg	0.5–3 K
	LS	–	0.5–3 K
	HS	–	1–3K
Timeliness (NWP)		1–3 hrs	1–3 hrs
Timeliness (Climate)		30–60 days	30–60 days
Time Domain (Climate)		> 5 years	> 5 years
Long-term Stability		< 2% RH/decade	< 0.1 K/decade
No. of profiles/ grid box/month		> 40	> 40

## Global Distribution of GNSS-LEO Occultations

ACE+ GNSS-LEO Occultation Events – Global Coverage in 1 Day



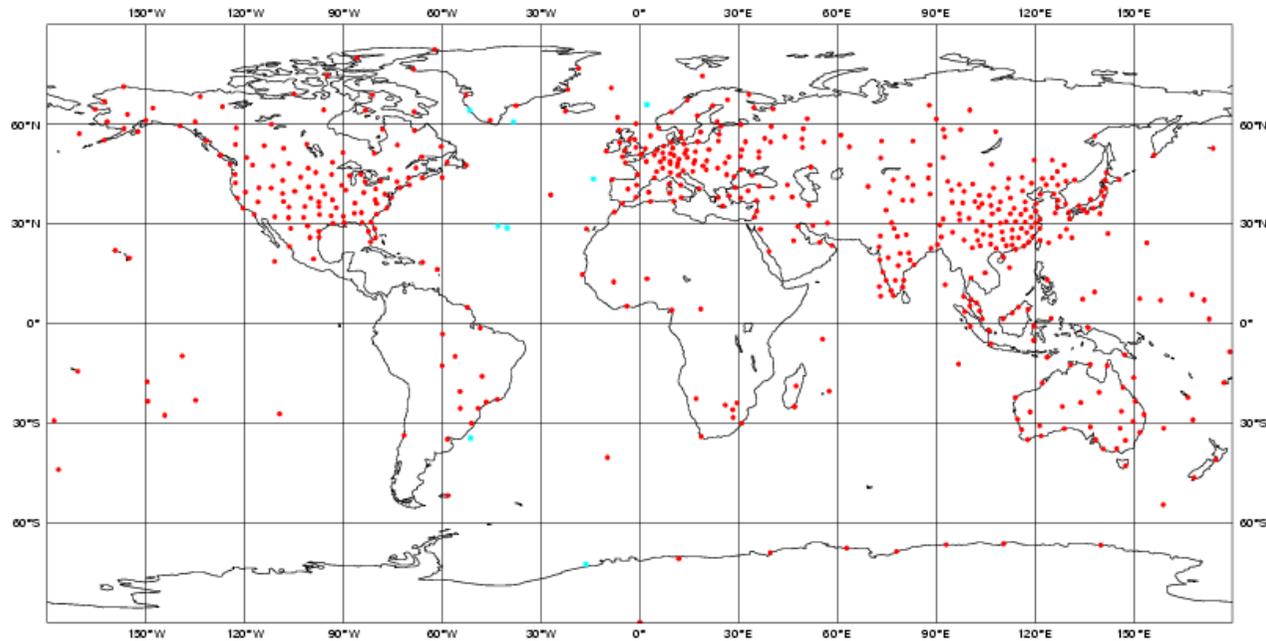
Produced by EGOPS © IGAM/UG et al. 1997-2001

No. of Occ. Events ( $\nabla$ Set+ $\Delta$ Rise,GPS+GAL): 5024 total, 2517 setting, 2507 rising.

# Distribution of NWP Radiosonde Observations

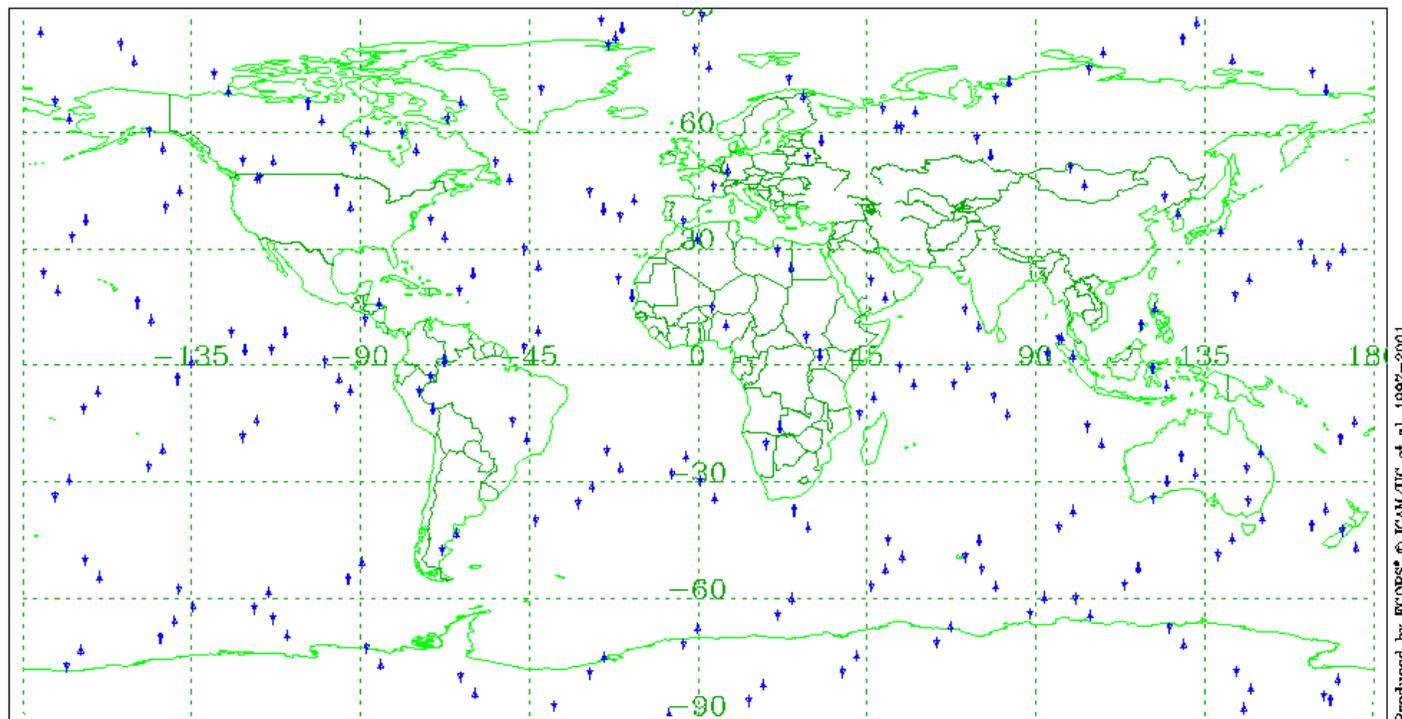
ECMWF Data Coverage  
15/DEC/1999 00 UTC

• 543 LAND  
• 8 SHIP

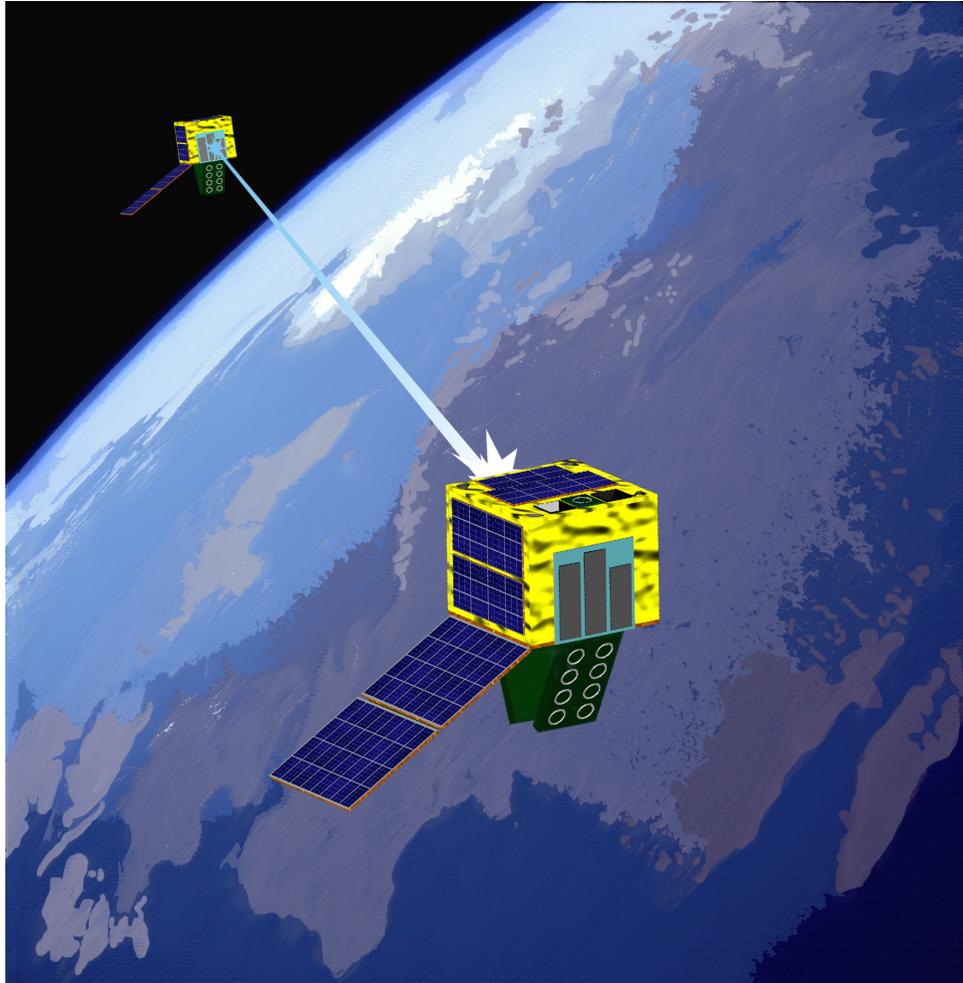


## Global Distribution of LEO-LEO Occultations

ACE+ LEO-LEO Occultation Events – Global Coverage in 1 Day



Number of Occ. Events ( $\nabla$ Set+ $\Delta$ Rise,LEO): 230 total, 115 setting, 115 rising.



- **Launch**
  - 2007/2008
- **Mission lifetime**
  - 5 years (2008 – 2012)