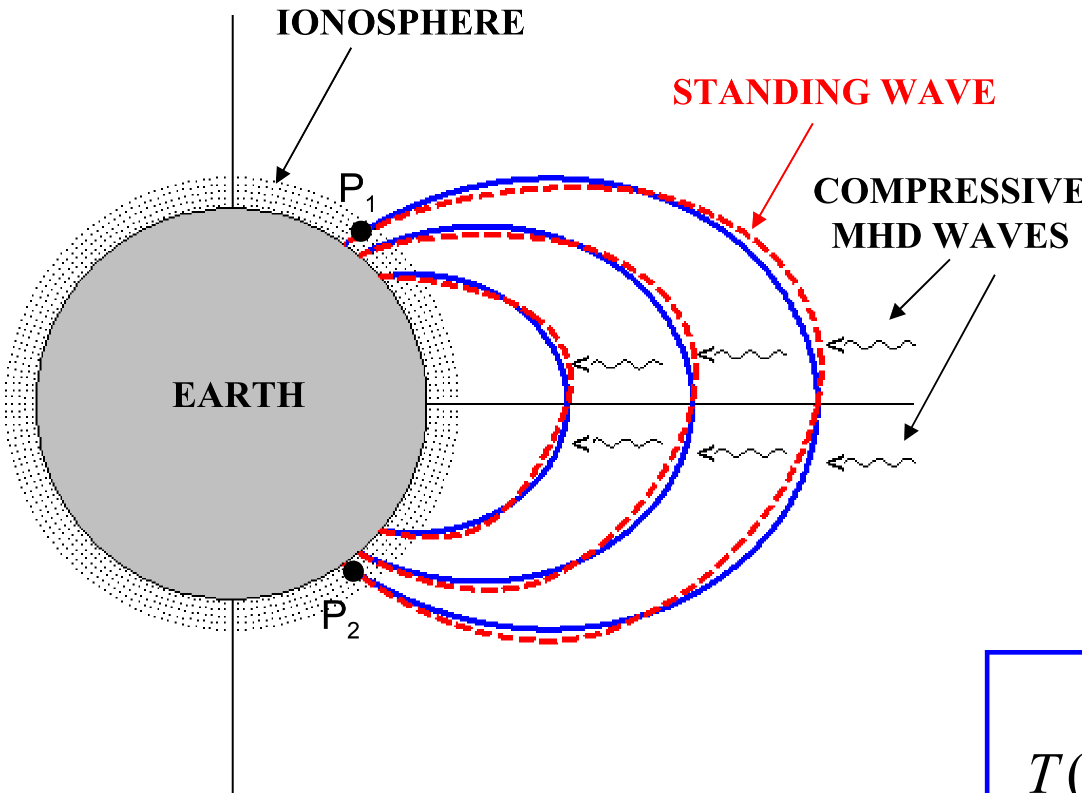
WP2: Retrieval of equatorial plasma mass densities by magnetometer arrays and cross-calibration

Participant	Person-months
UNIVAQ	**28**
ELGI	**20**
IGPAS	**16**
HMO	**7**
ELTE	**4**
NERC–BAS	**2**
UO	**2**
UOULU	**1**
LANL	**1**
NMT	**?**
FMI	

Geomagnetic Field Line Resonances (FLR)



$$T(L) \cong \int_{P_1}^{P_2} \frac{ds}{V_A(s)}$$

$\mathbf{V_A}$: Alfvén velocity

$$T(L) = 2\mu_o \int_{P_1}^{P_2} \frac{\rho^{1/2}(s)}{B(s)}\, ds$$

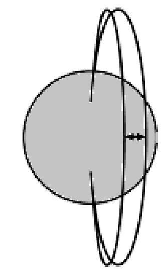
Whistlers $\rightarrow$ electron density

ULF waves $\rightarrow$ mass density

Inference of the plasma mass density from field line eigenfrequencies

Standard procedure for low and middle latitudes:

Assumption: Observed FLR frequencies (f_R) correspond to the axisymmetric **toroidal** mode eigenfrequencies in a **dipole** field.



Governing equation:

$$d^2E/dz^2 + \lambda (1- z^2)^6 \rho(z)/\rho_o E = 0$$

E : wave electric field
z = cos (θ), **θ**: colatitude
ρ : mass density along the field line
ρ_o: equatorial mass density

Eigenvalues λ are found imposing:

1) the boundary condition: **E = 0** at the altitude (100-200 km) where the wave is reflected

2) A given functional form for the mass density along the field line.

Common assumption: $\rho(r)/\rho_o = (r / r_o)^{-m}$

For any given **L- shell** and **m** value, the inferred **equatorial** mass density is:

$$\boxed{\rho_o\,[\mathrm{amu/cc}] = \frac{A_{L,m}}{f_R^{\,2}\,[\mathrm{mHz}]}}$$

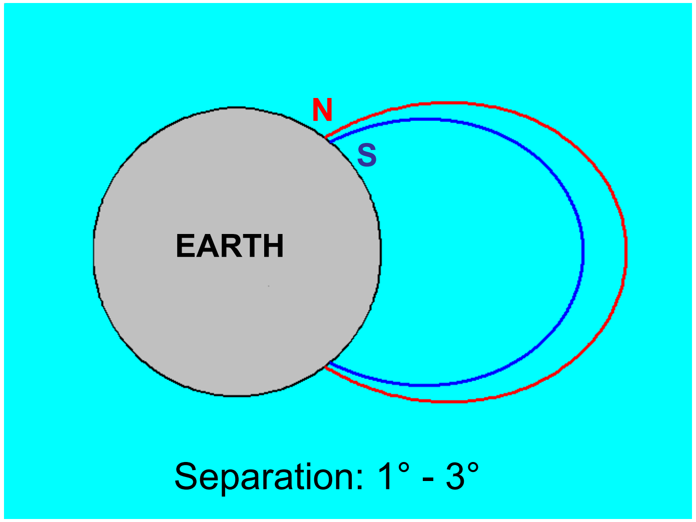
$$A_{L,m} = \frac{K\lambda_{L,m}}{L^8}, \qquad K = \mathrm{const.} \cong 2.9\times 10^8$$

Inference of the equatorial plasma mass density at L = 1.61

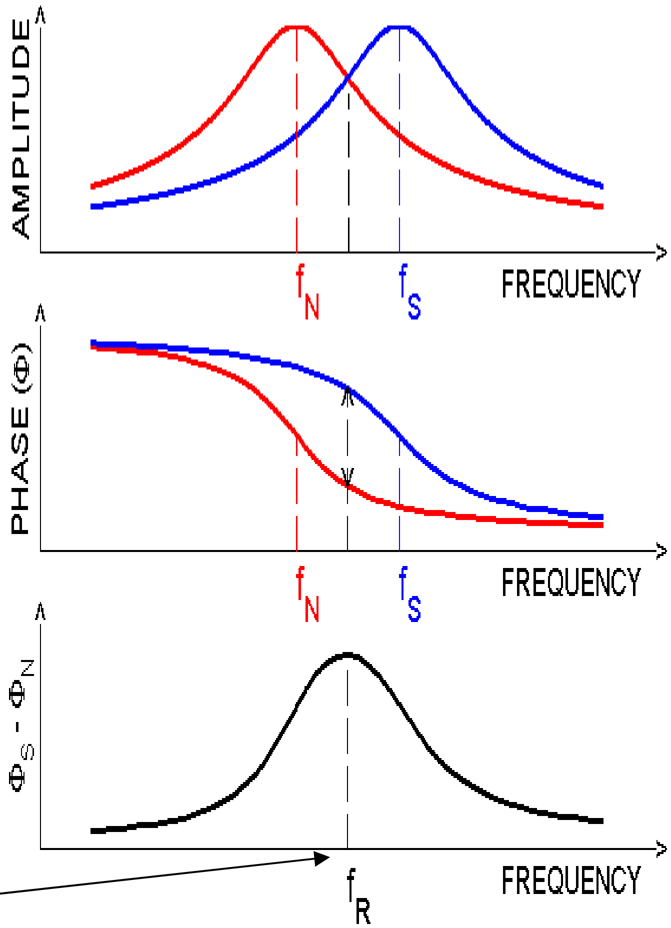
Numerical simulations for different solar, geomagnetic and LT conditions provide:

$$\rho_{\mathrm{o}}\,[\mathrm{amu/cc}] = \frac{(4 \pm 1) \times 10^{7}}{f_R^{\,2}\,[\mathrm{mHz}]} \longrightarrow \quad 3 < m < 10$$

GRADIENT METHOD FOR DETECTING FIELD LINE RESONANCES FROM GROUND-BASED ULF MEASUREMENTS



FREQUENCY RESPONSE OF TWO OSCILLATORS



Higher latitude field line → Lower resonance frequency (f_N)

Lower latitude field line → Higher resonance frequency (f_S)

CROSS-PHASE TECHNIQUE

Resonance frequency at the middle point.
Identified by a maximum in the phase difference

Map of operating / planned EMMA stations

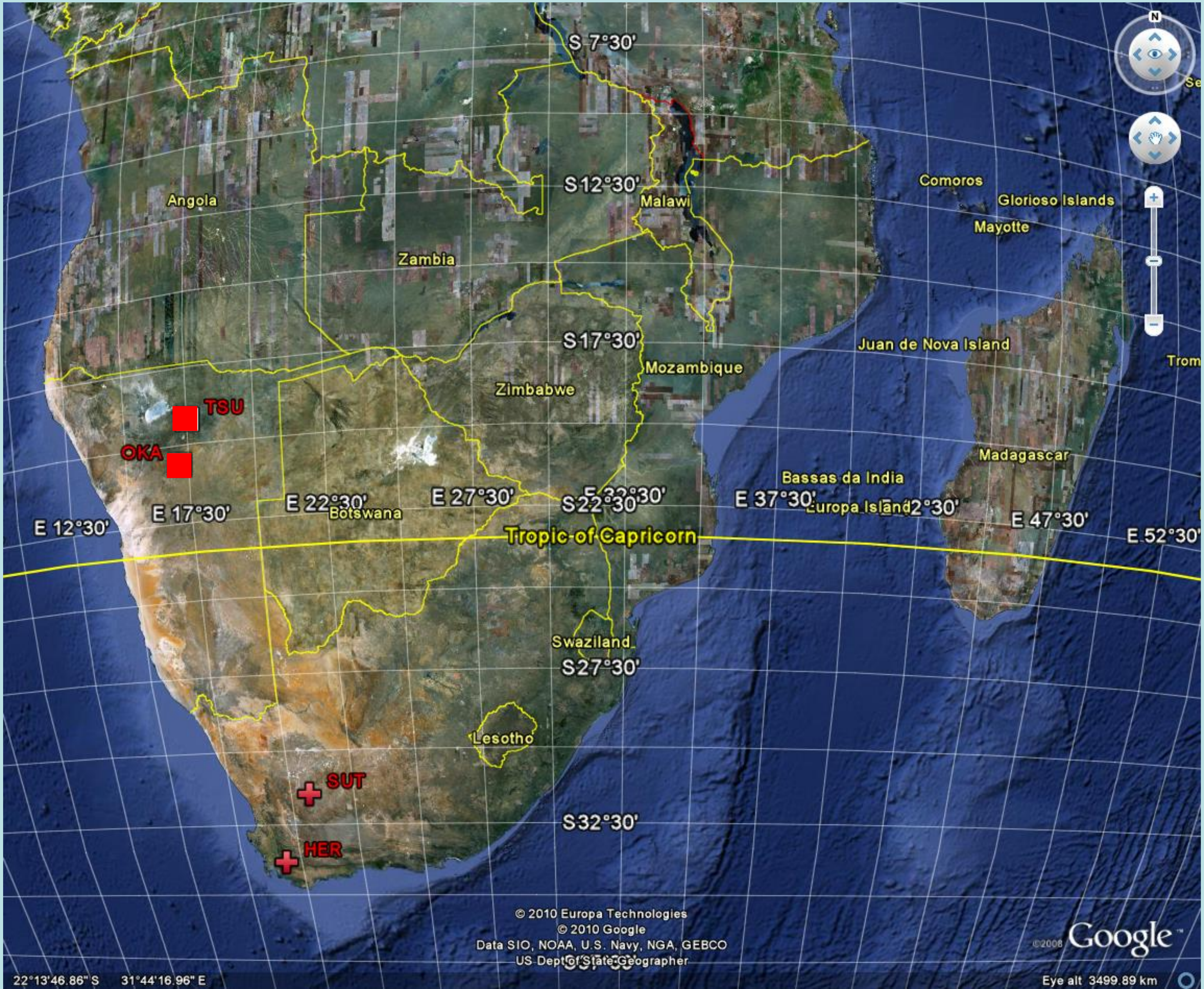
Δ SEGMA

+ MM100

□ IMAGE

■ planned new stations

Map of operating (+) / planned (■) South Africa stations



WP2 objectives

1. Unify and extend SEGMA, MM100 and IMAGE networks into EMMA (+ S.Africa stations) to have better latitudinal coverage (3 new stations by month 12, other 4 new stations by month 24): ELGI, IGPAS, HMO

2. Develop an automatic FLR identification method [month 24]: UNIVAQ, ELGI, IGPAS

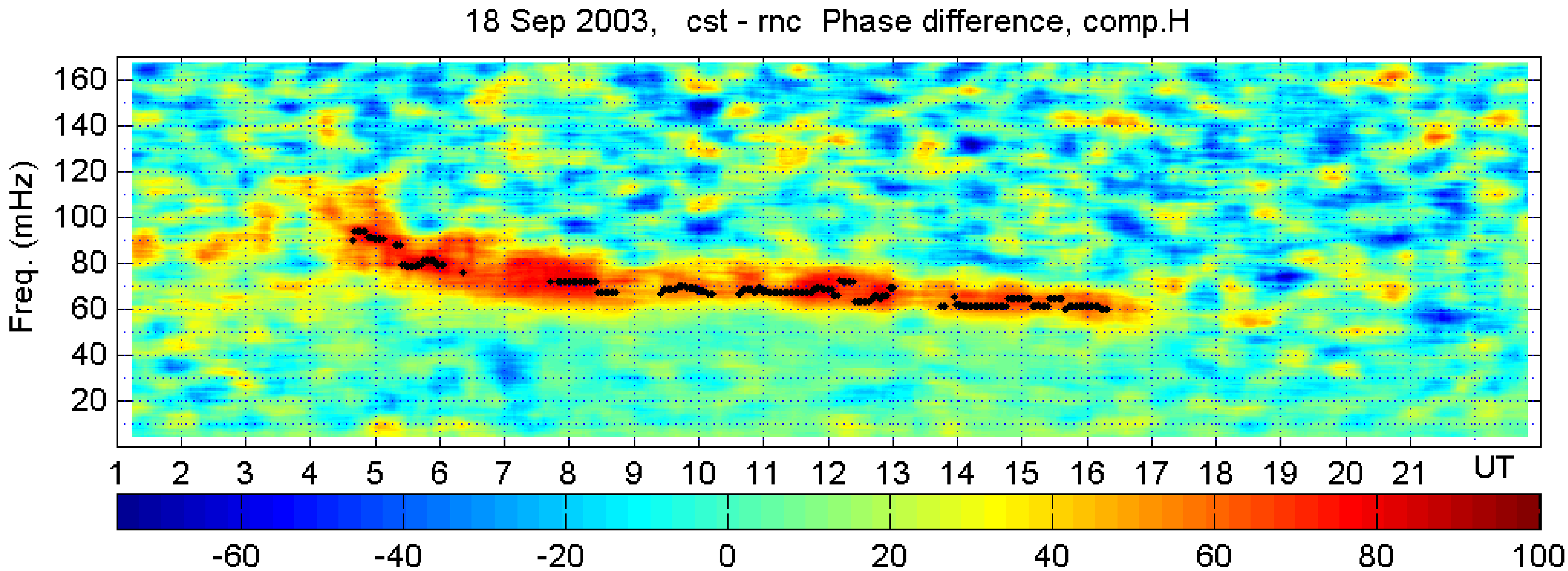
3. Develop an automatic FLR inversion method [month 24]: UNIVAQ, ELGI, IGPAS, (NMT)

4. Develop all EMMA stations to work in quasi-real-time mode of operation [month 42]:
   ELGI, IGPAS, HMO, UNIVAQ, FMI

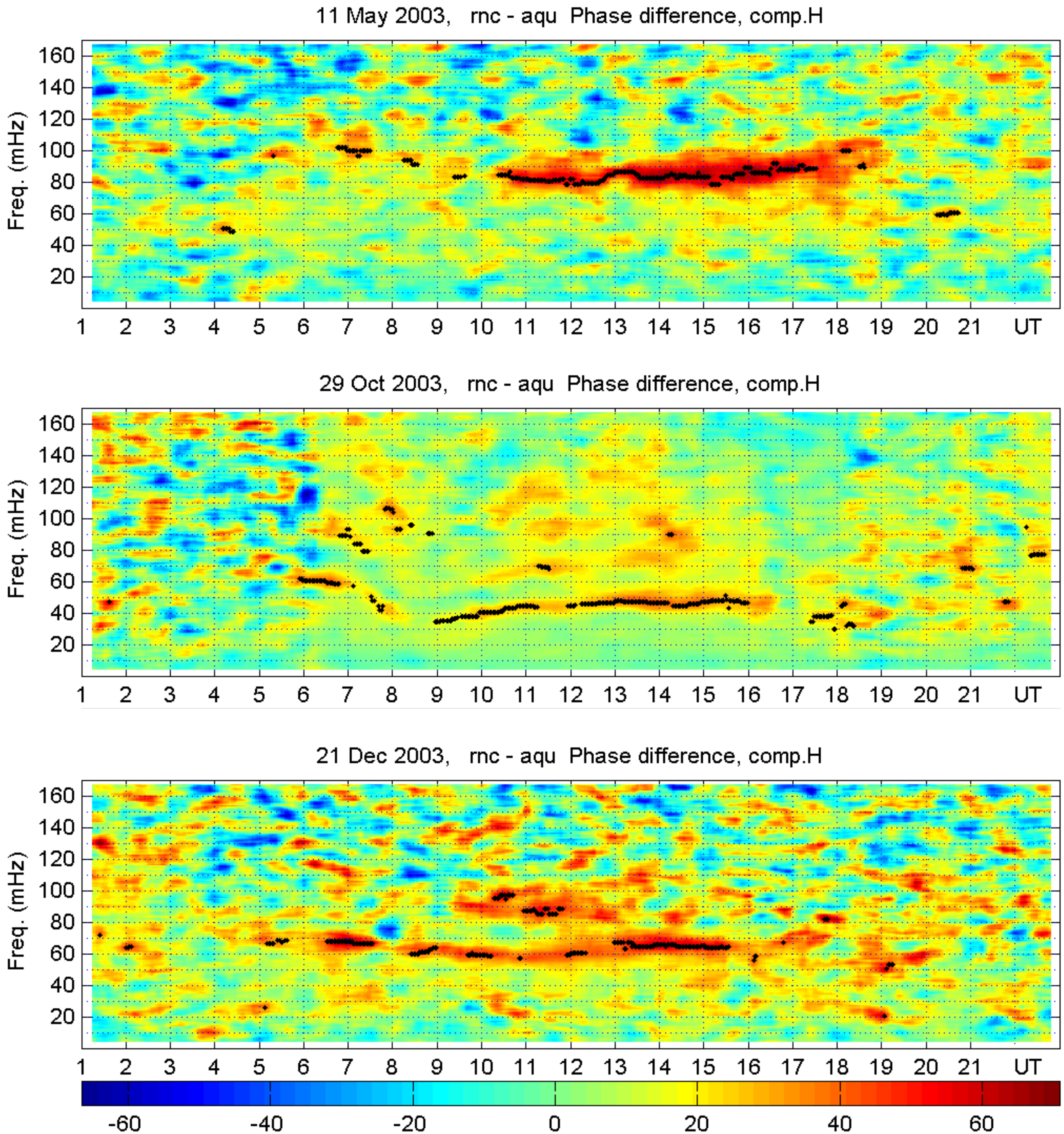
5. Evaluate relative abundances of heavy ions in the plasma composition from simultaneous determinations of mass density (FLR method) and elect. density (whistler met.) [month 42]:
   ELGI, UNIVAQ, ELTE, (LANL, NERC-BAS, NMT, UO, HMO, UOULU)

Automated selection of FLR frequencies (objective 2)

UNIVAQ, ELGI, IGPAS   delivery date: month 24



- Current algorithms (from *Berube et al. 2003*) used by UNIVAQ and ELGI: to be improved, and fully automatized.
- ~1 mHz frequency resolution, ~ 20 min time resolution.
- Specific version for each station pair (because of different latitude, interstation separation, ground conductivity, noise level, etc.).
- All versions running on a central server where data must arrive in quasi-real time.



11 May 2003, rnc - aqu Phase difference, comp.H
Freq. (mHz)
160
140
120
100
80
60
40
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 UT
29 Oct 2003, rnc - aqu Phase difference, comp.H
Freq. (mHz)
160
140
120
100
80
60
40
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 UT
21 Dec 2003, rnc - aqu Phase difference, comp.H
Freq. (mHz)
160
140
120
100
80
60
40
20
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 UT
-60 -40 -20 0 20 40 60

Automatic FLR inversion (objective 3)

UNIVAQ, ELGI, IGPAS, (NMT)   delivery date: month 24

The inversion algorithm has to convert FLR frequencies into estimates of the equatorial plasma mass density ($1.6 < L < 6.7$).

Need to consider geomagnetic field geometry (*Tsyganenko, Singer et al., 1981*) more realistic than dipole geometry; important at high latitudes, and even at middle latitudes during severe geomagnetic storms.

Realistic plasma distribution models for low latitudes (power law not quite good).

All magnetometer stations working in quasi-real-time (objective 4)

ELGI, IGPAS, HMO, UNIVAQ, FMI delivery date: month 42

Upgrading the DAQ hardware and software to provide real-time accessibility of the data.

Data from each station transferred every 15 min to the central server, where they will be processed to get FLR frequencies and plasma mass densities.

Cross-calibration method for whistlers and FLRs (objective 5)

ELGI, UNIVAQ, ELTE, (LANL, NERC-BAS, NMT, UO, HMO, UOULU)   delivery date: month 42

When simultaneously available, plasma mass densities from FLRs and electron densities from whistlers will be cross-correlated (for separate magnetospheric activity conditions), both for validating the two methods, and for obtaining evaluations on the relative abundances of heavy ions.

In addition, comparisons with in-situ satellite measurements (e.g., MPA data from LANL) will be extremely useful for a direct validation.

At the end, a procedure has to be developed for weighting the data from the two methods.

Estimation of average ion mass from synchronous measurements

Heilig et al. (IAGA Assembly, 2009)