# Impact of ULF Wave Power on the Ionosphere

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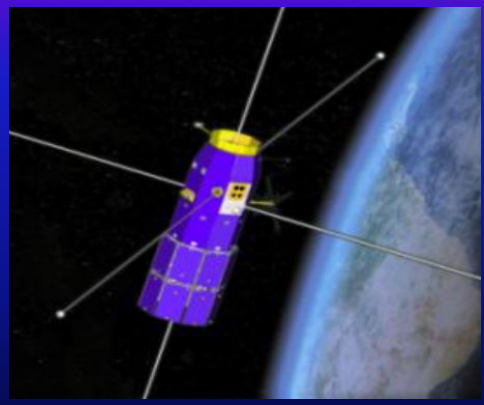
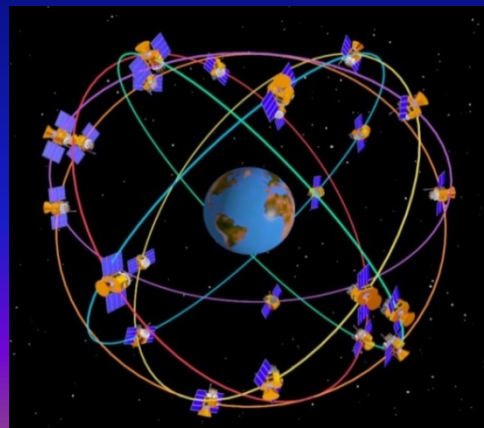
# Outline

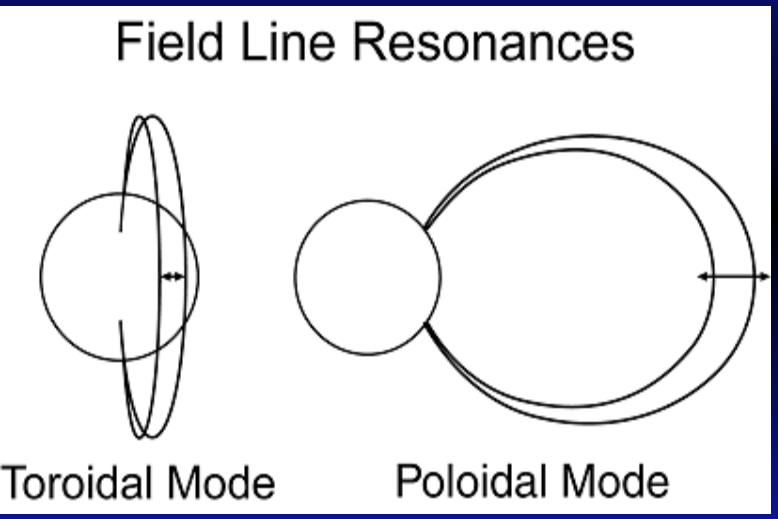
- What is the source of ULF wave?
- Do the ULF waves cause density fluctuations?
- Does ULF related density undulation cause scintillation?
- DP2 current and its impact at the equator



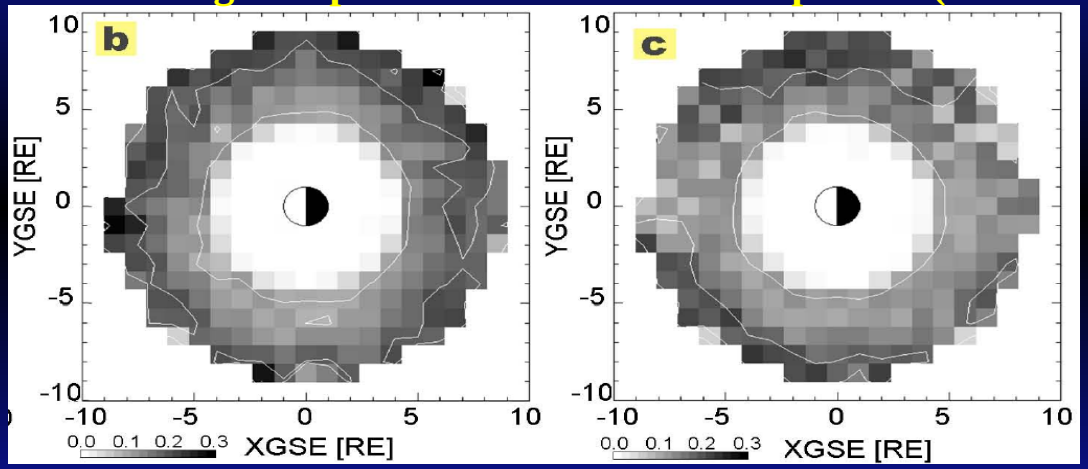


# Where does the ULF wave came from?

- The periodic SW dynamic pressure oscillations slowly alter the size of the magnetospheric cavity, causing the generation of poloidal ULF wave.
- The change in SW azimuthal flow direction (usually accompanying shocks) can excite Kelvin-Helmholtz (KH) instabilities at the magnetopause, which in turn causes the generation of Toroidal mode ULF wave.




Active Magnetospheric Particle Tracer Explorers (AMPTE)



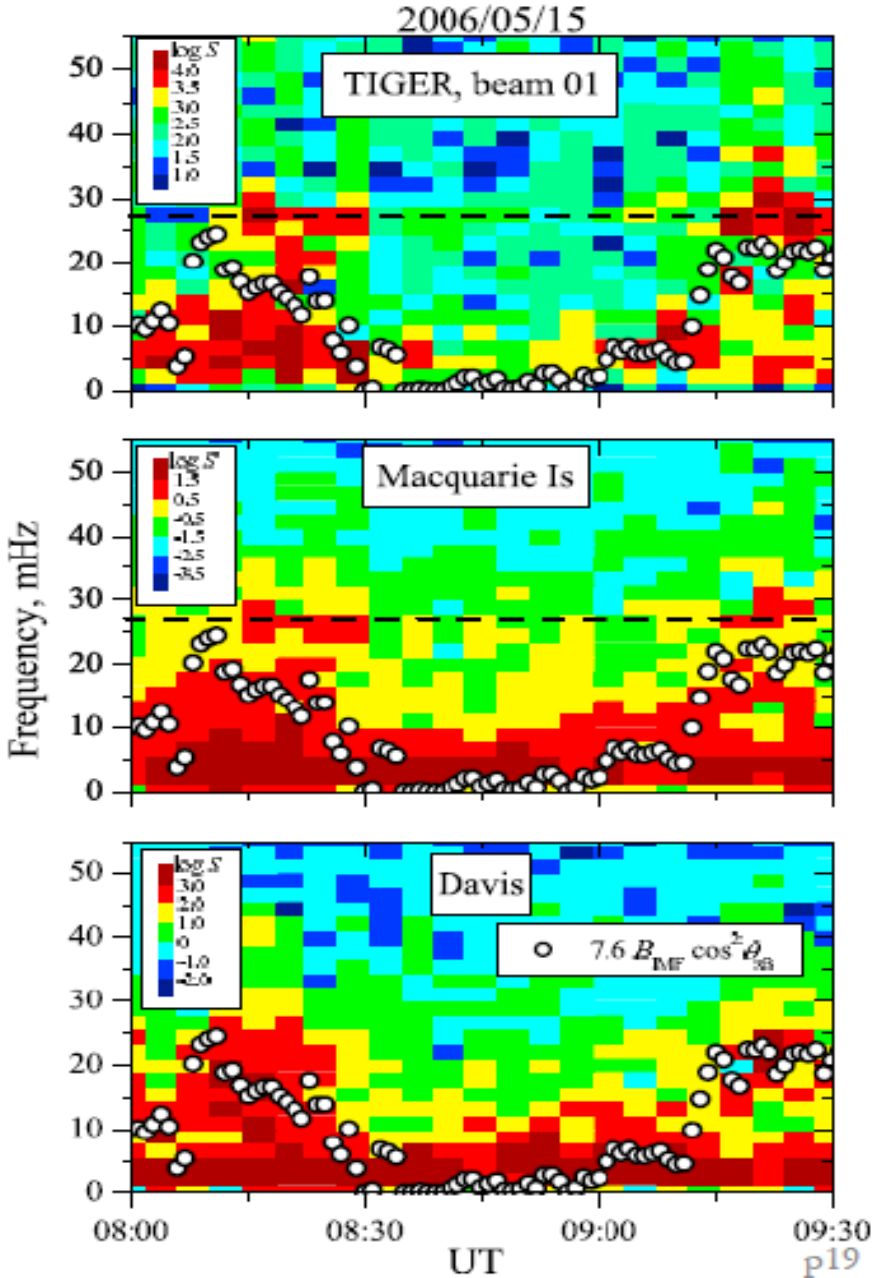

*Poloidal Pc5 &* *Toroidal Pc5*

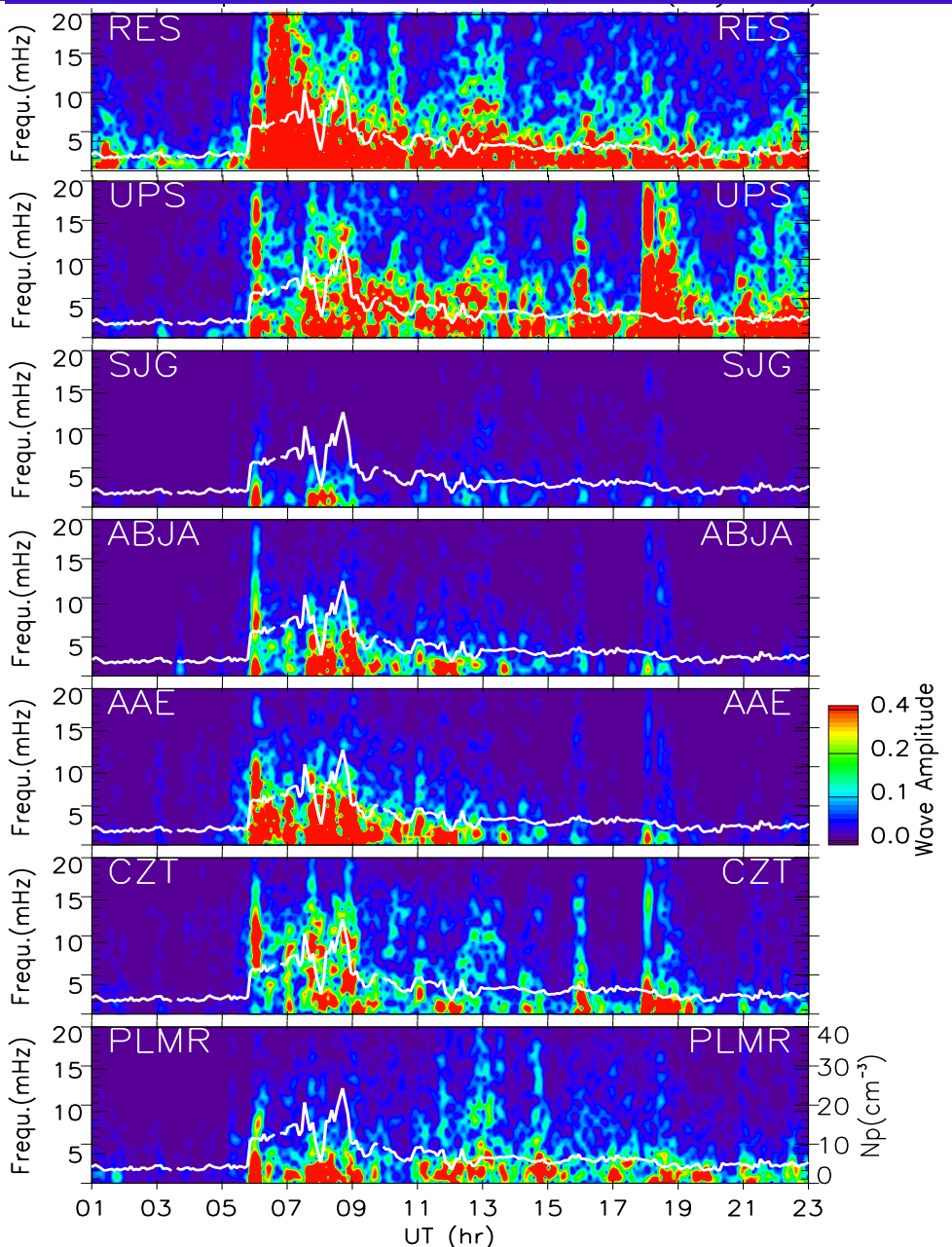
***wave*** **occurrence rates [*Agapitov & Cheremnykh*, 2013]**

## The question is, why do we care about it?

**To Understand the impact of its energy that comes down to the ionosphere and cause the density to fluctuate!**

# ULF wave signature on the ground

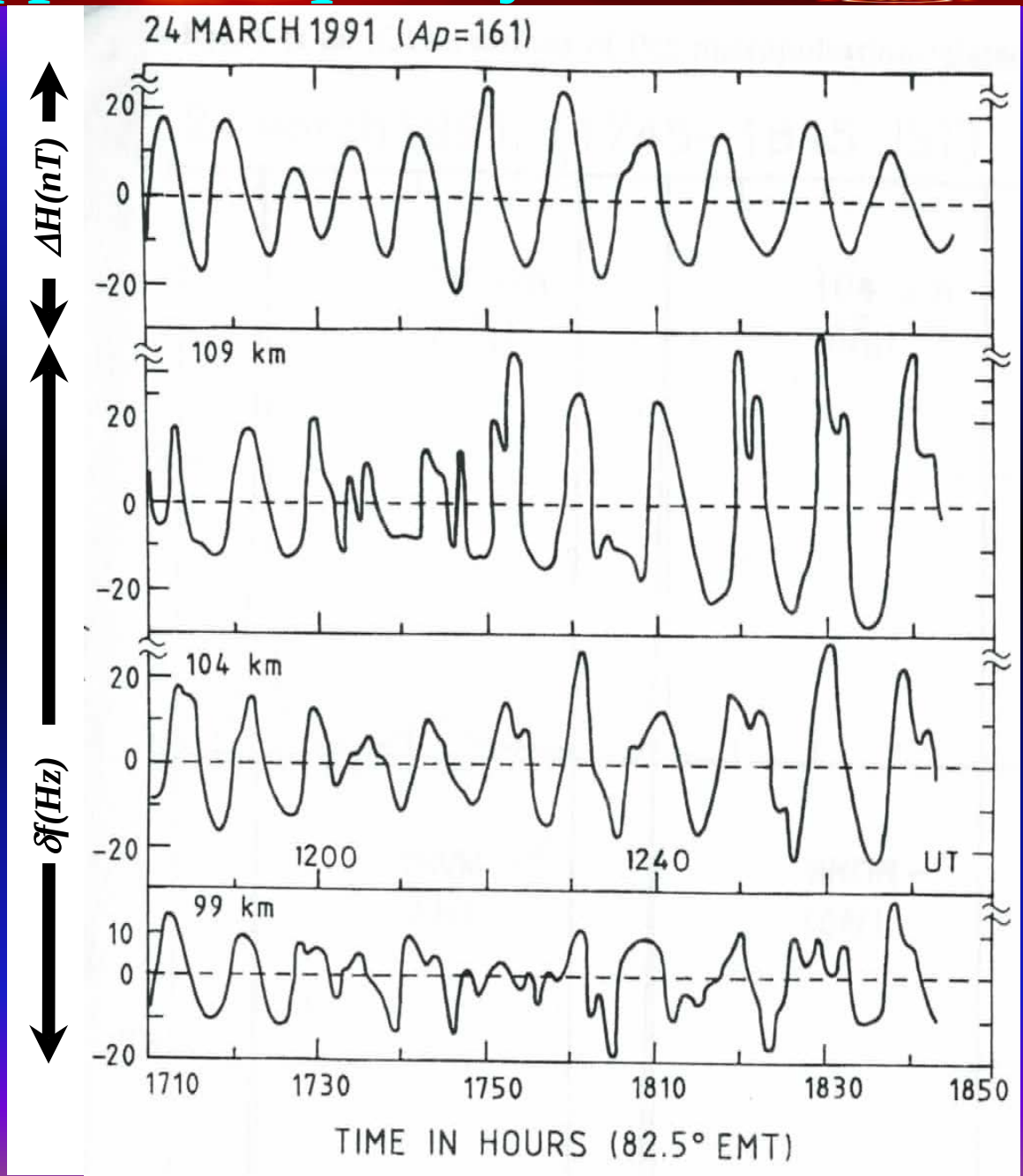


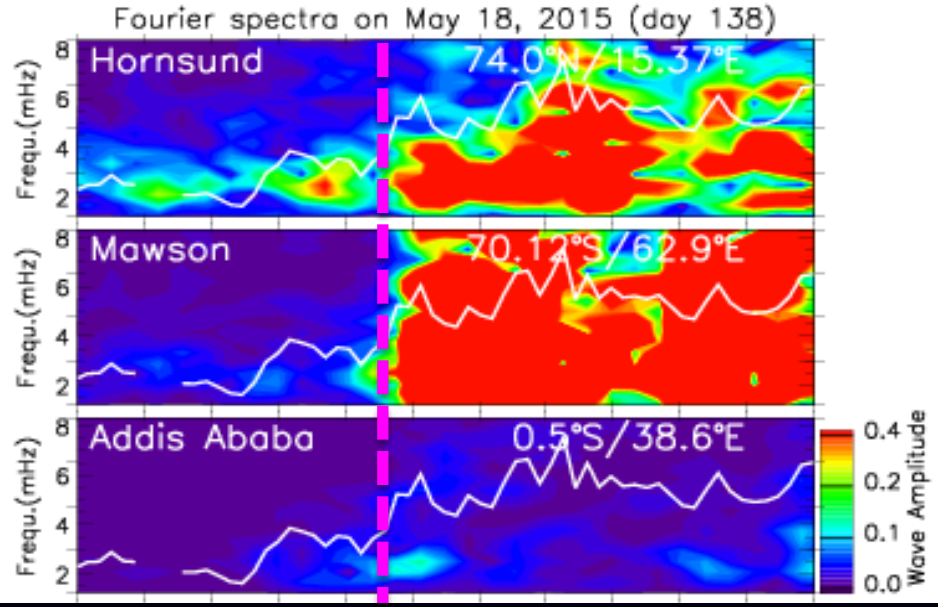
# ULF wave and Doppler frequency variations

**Time series of Doppler frequency variation at three different altitudes, observed by 54.95 MHz coherent backscatter radar!**

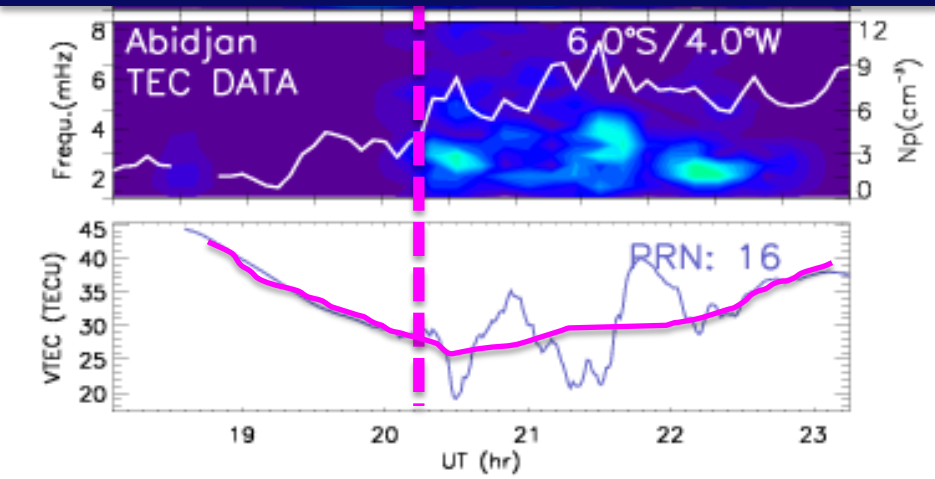
***(Reddy et al., AG, 1994)***

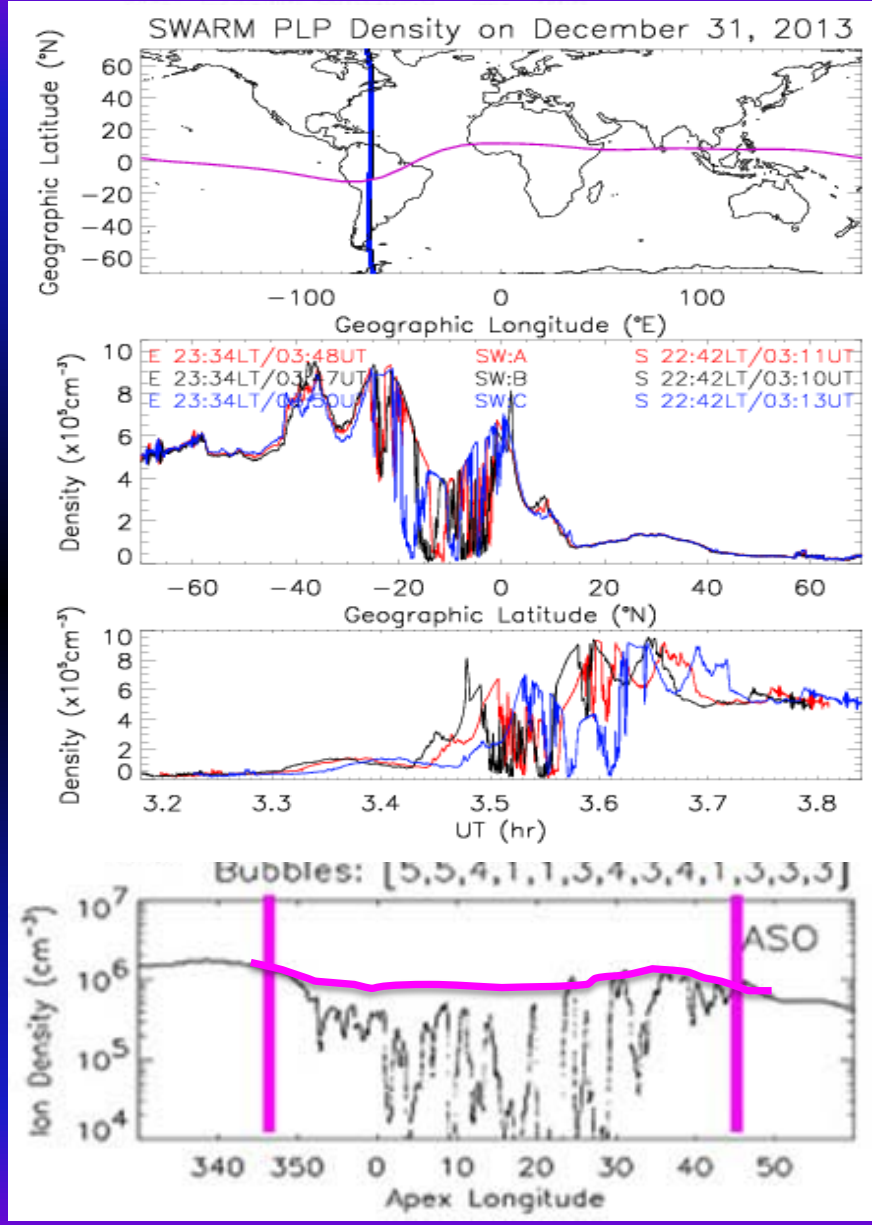


# ULF wave associated density fluctuation




## *ULF wave in the Pc5 range*

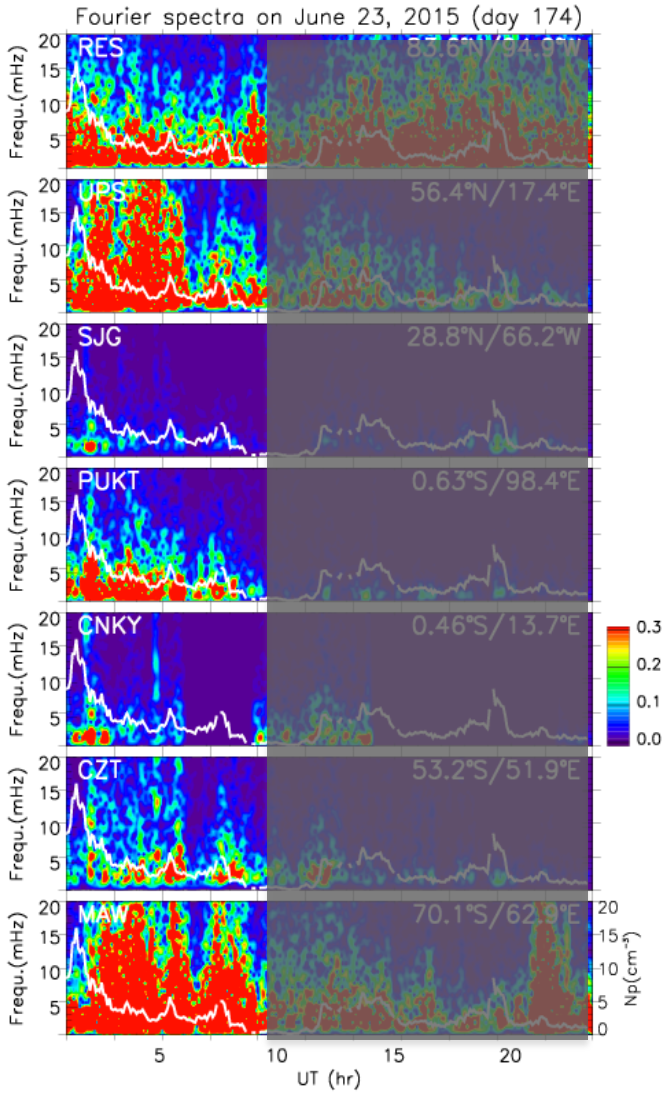



*Hei et al., JGR, 2005*

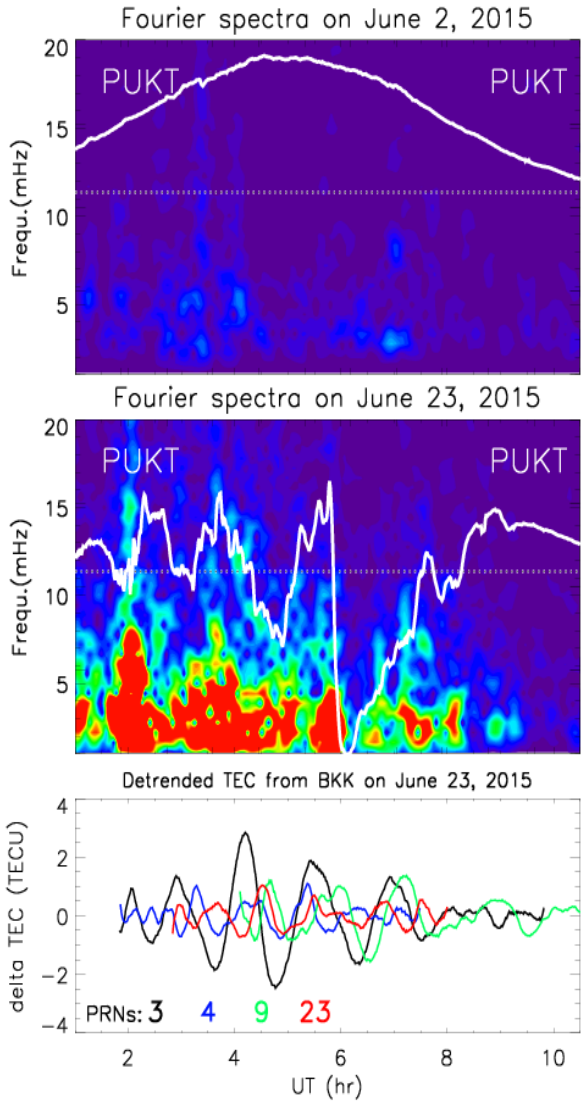
# ULF wave and density irregularity correlation

## ULF wave penetration on 23 June 2015

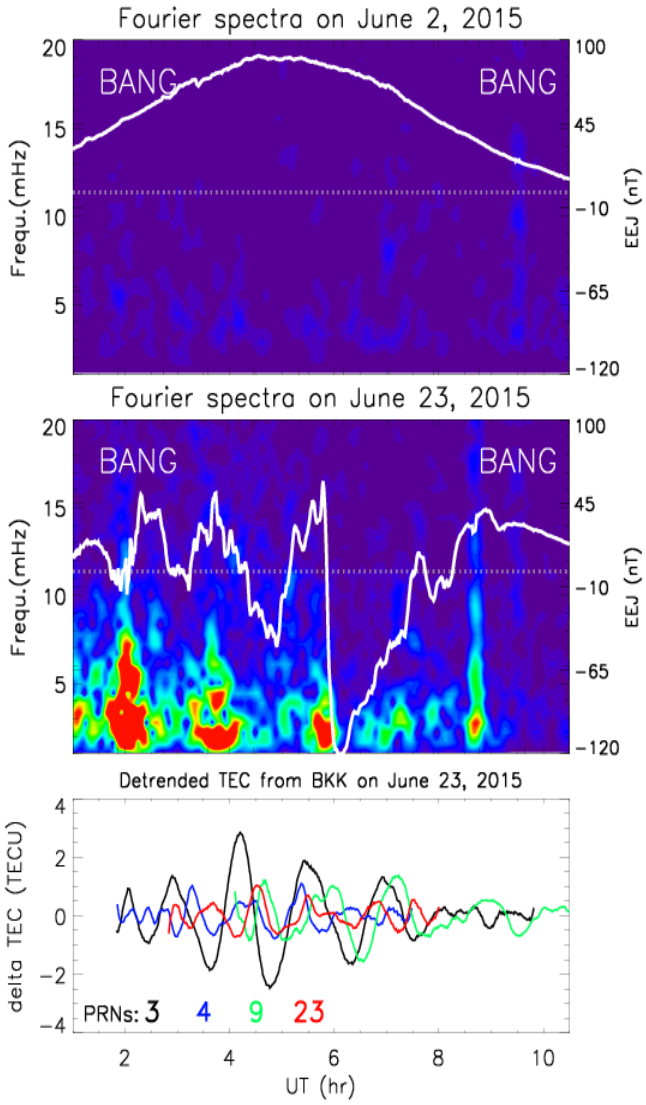



## Ionosphere response to ULF wave

### On 23 June at Phuket



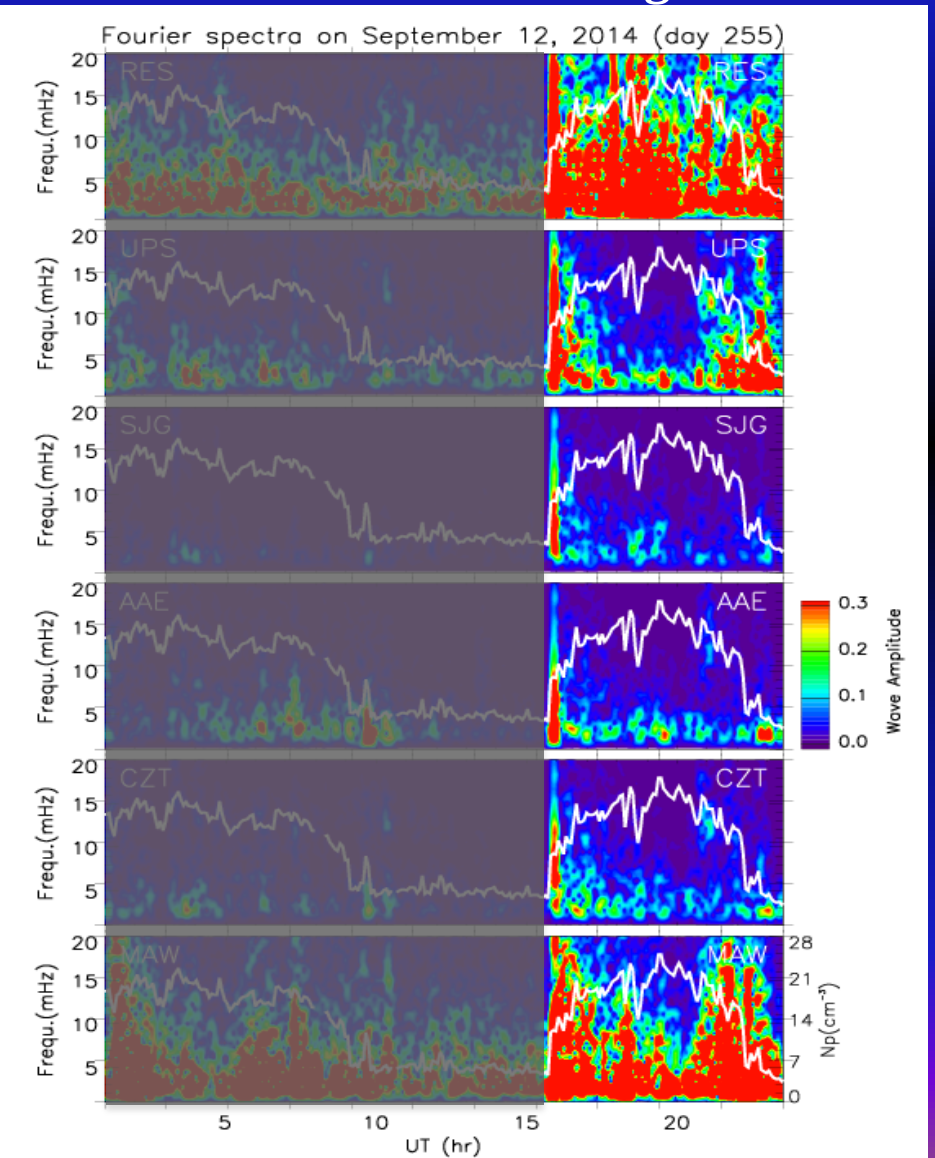

### On 23 June at Bangkok



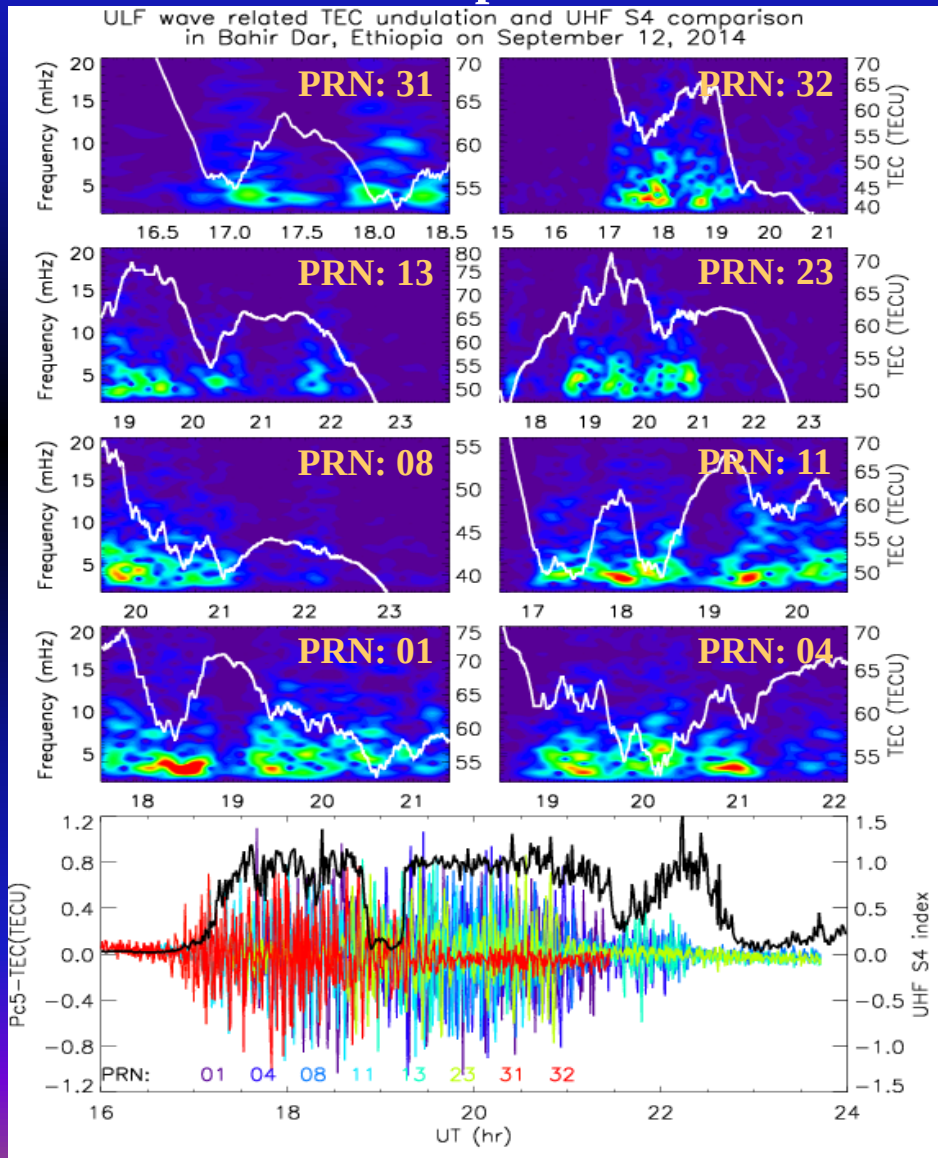

LT = UT +7

# Solar wind-magnetosphere-ionosphere coupling impact on equatorial ionosphere

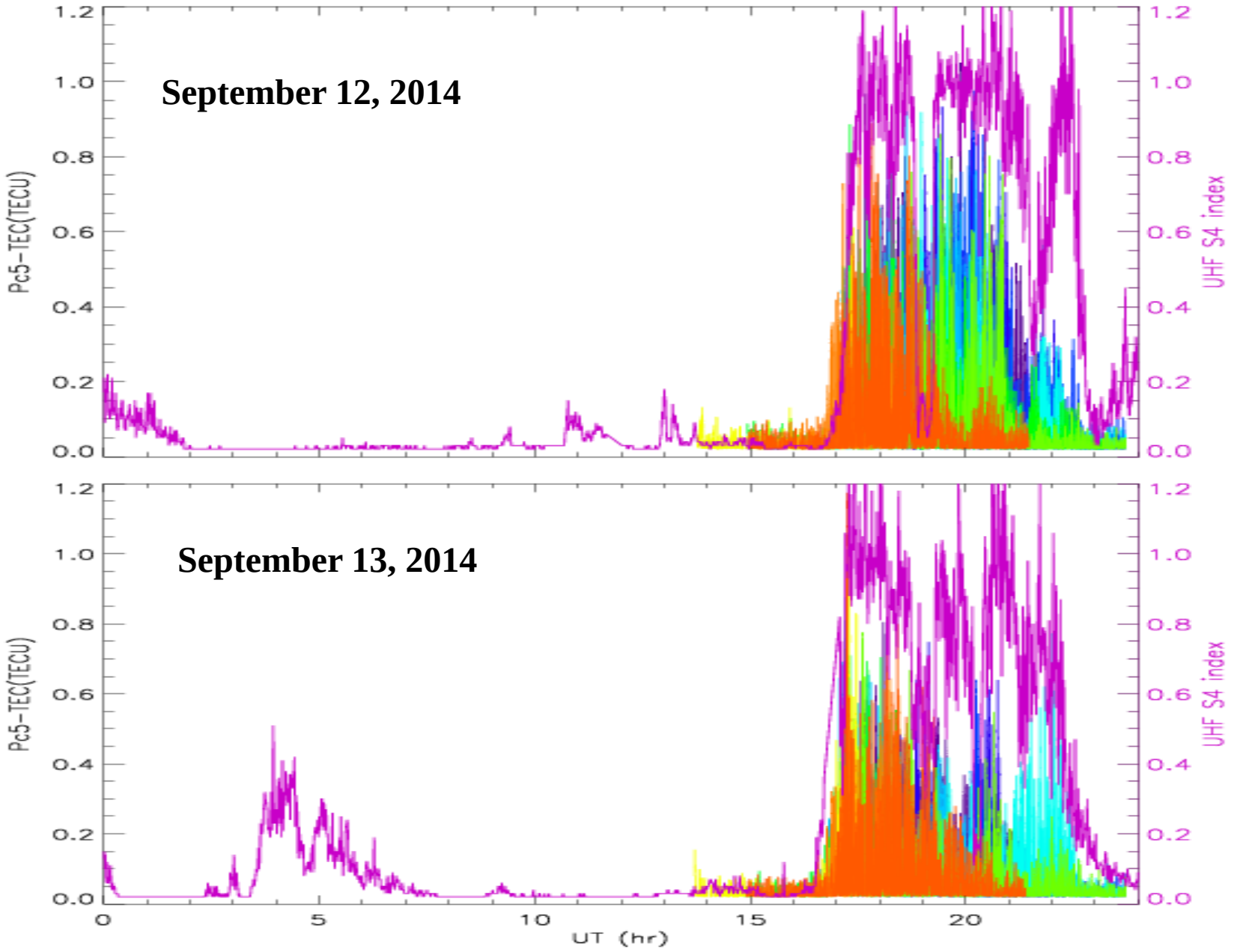
## ULF wave from chain of magnetometers



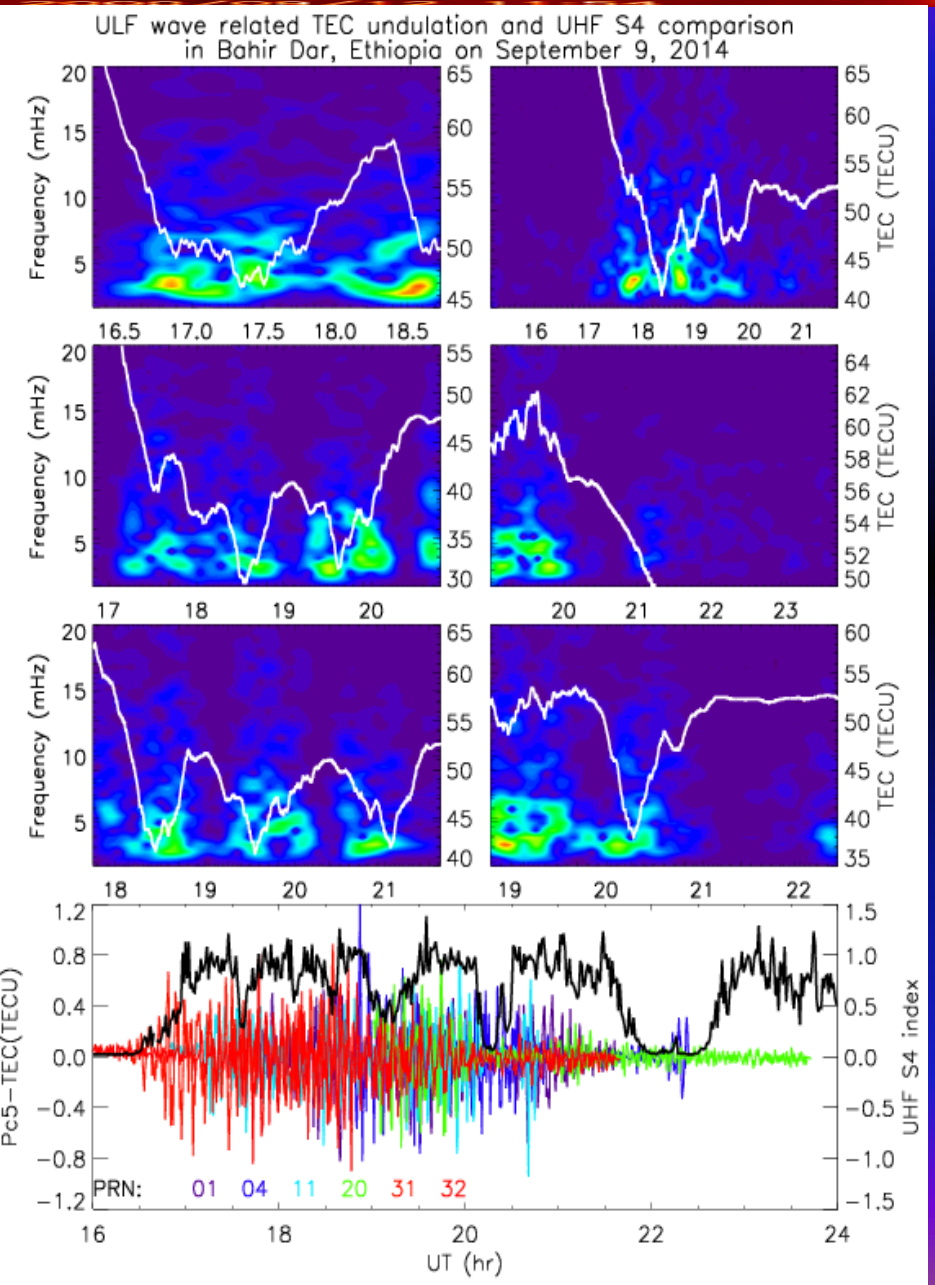

## ULF wave impact on TEC

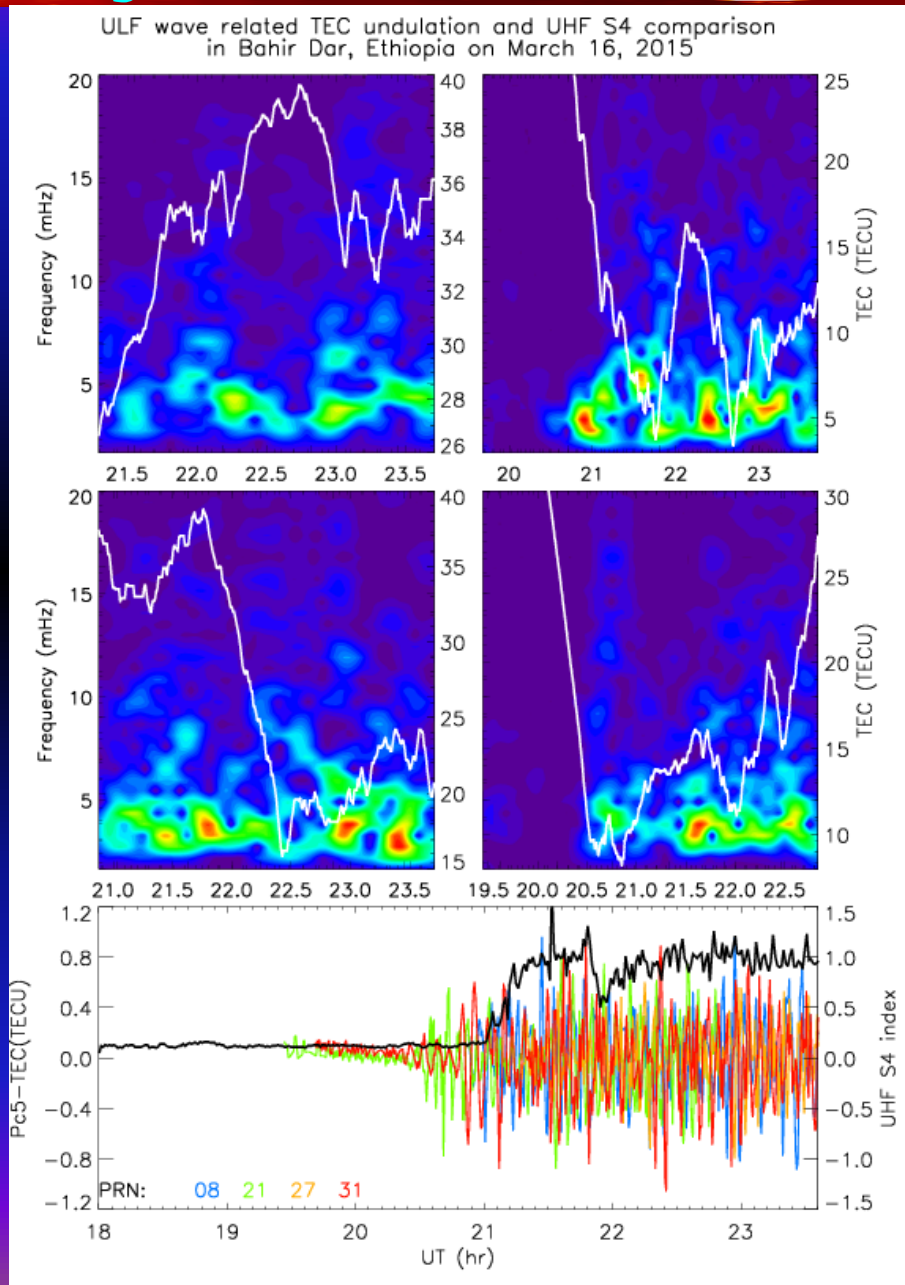


# TEC perturbation amplitude and S4 index



# TEC modulation by ULF waves



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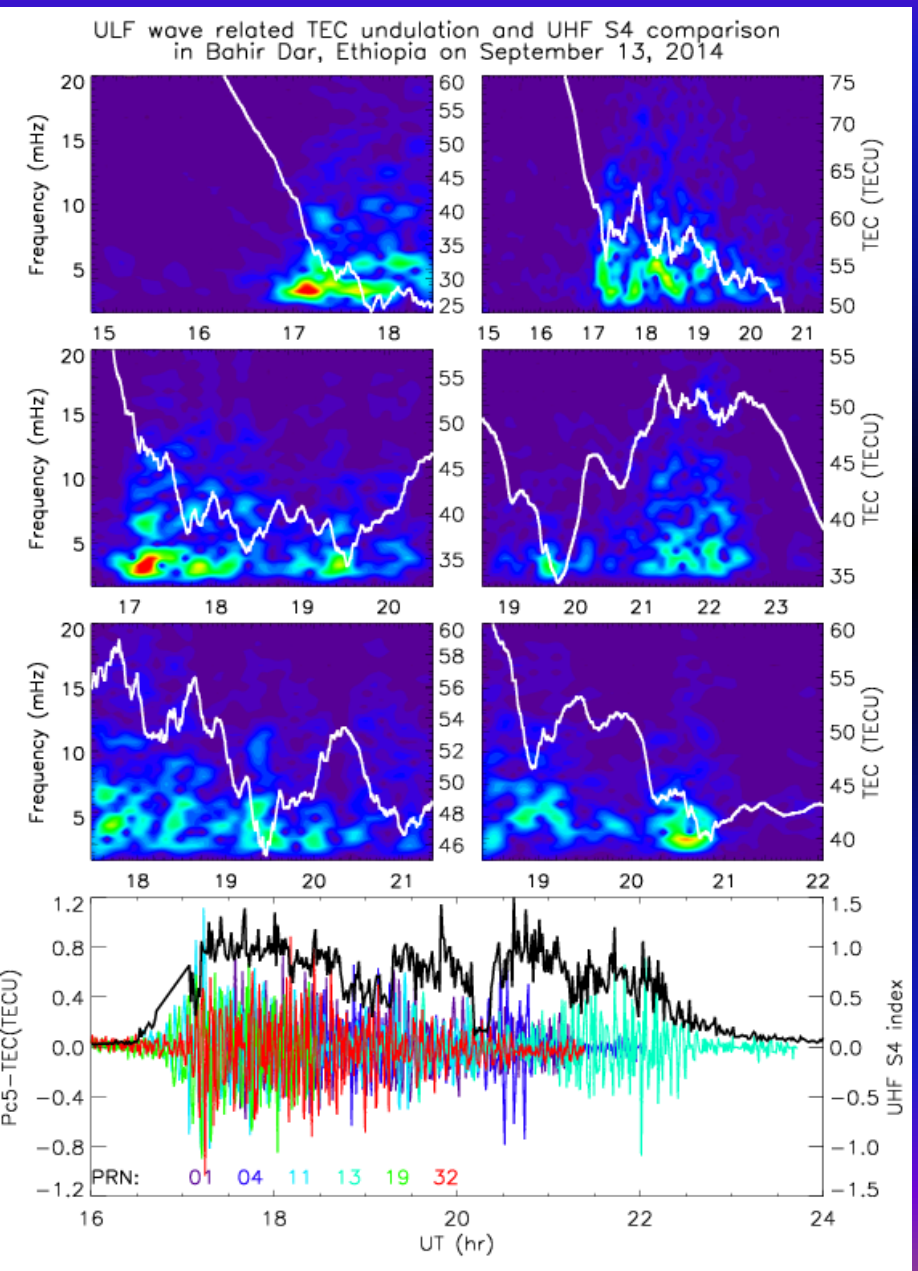
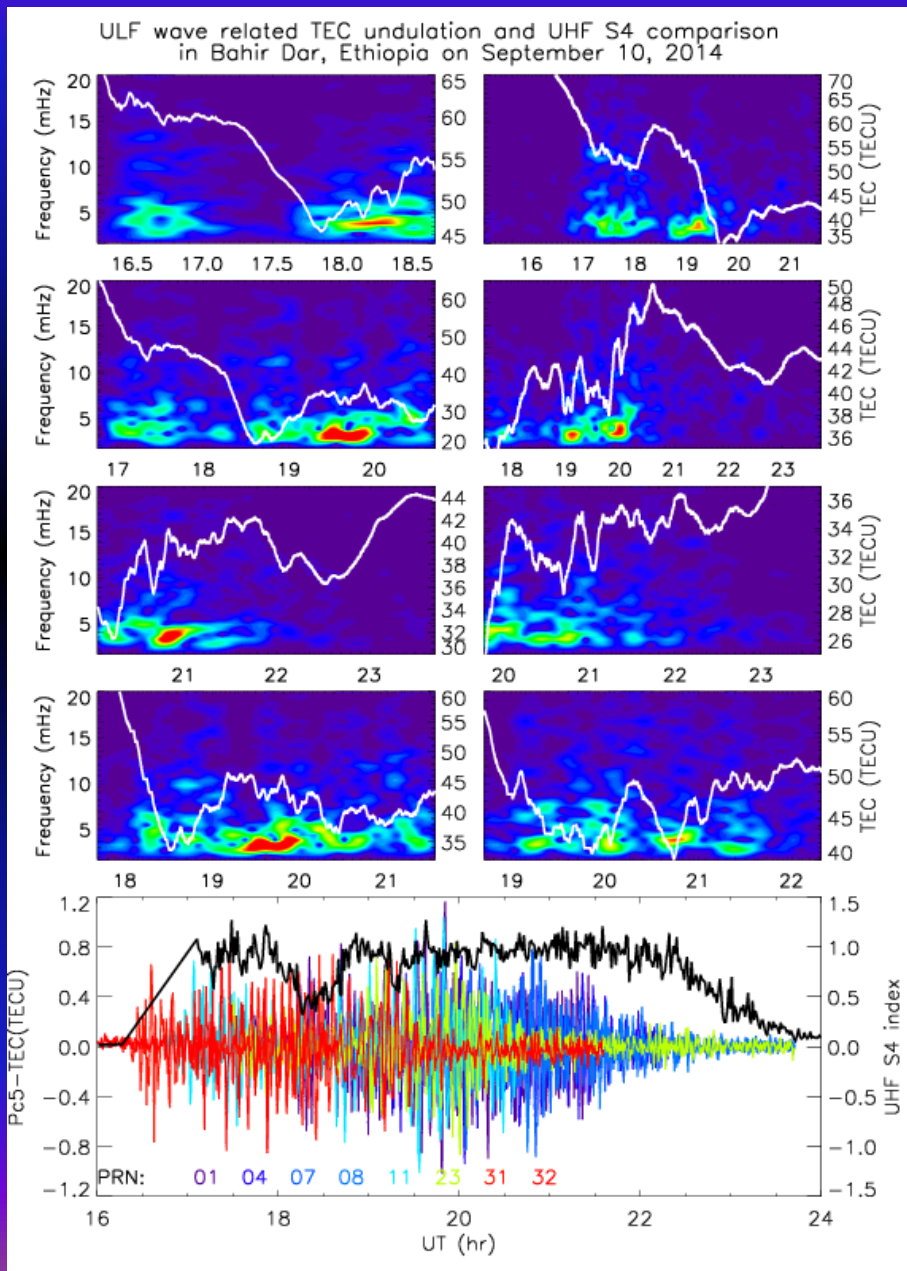


# What is the possible mechanisms?

- **When the Alfven/ULF wave enters into the region of magnetized plasma (e.g., ionosphere), it produces electric fields and thus oscillating drift.**

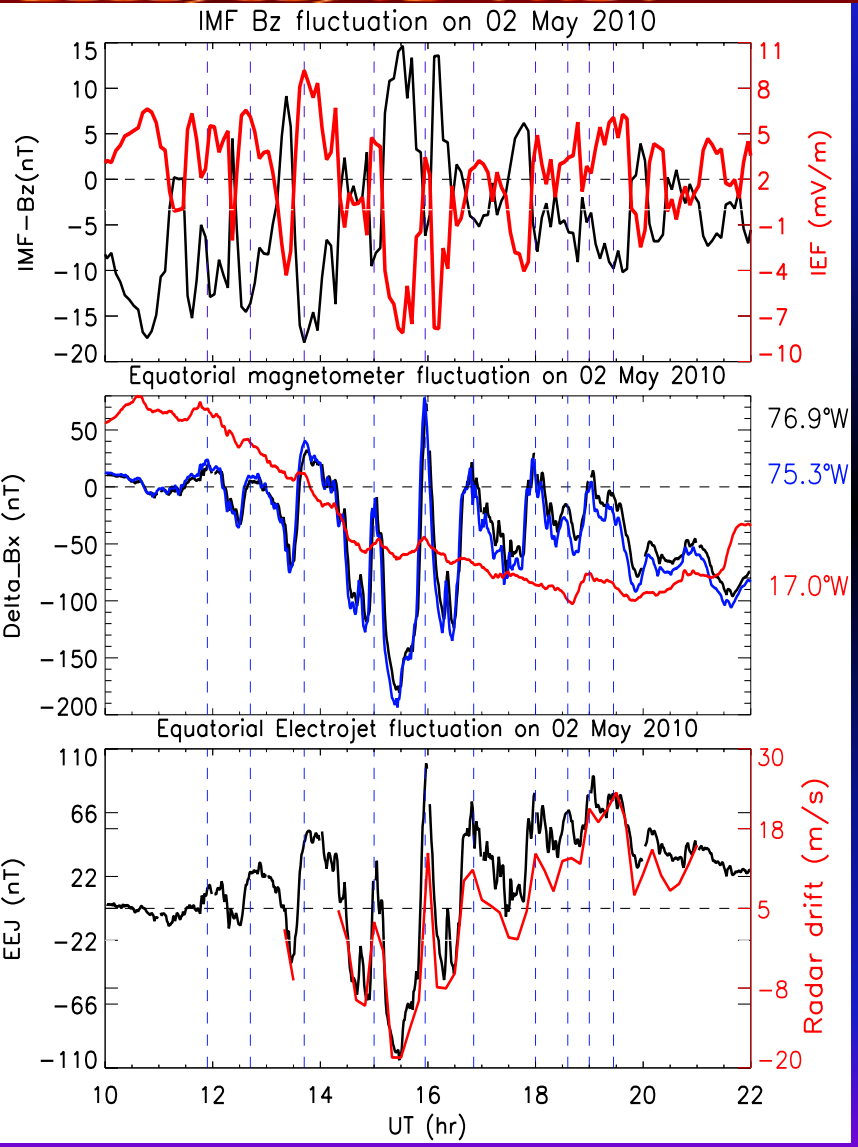
$$V_z = E_y CosI/B_0 \text{; } I \text{ (mag. field inclination)}$$

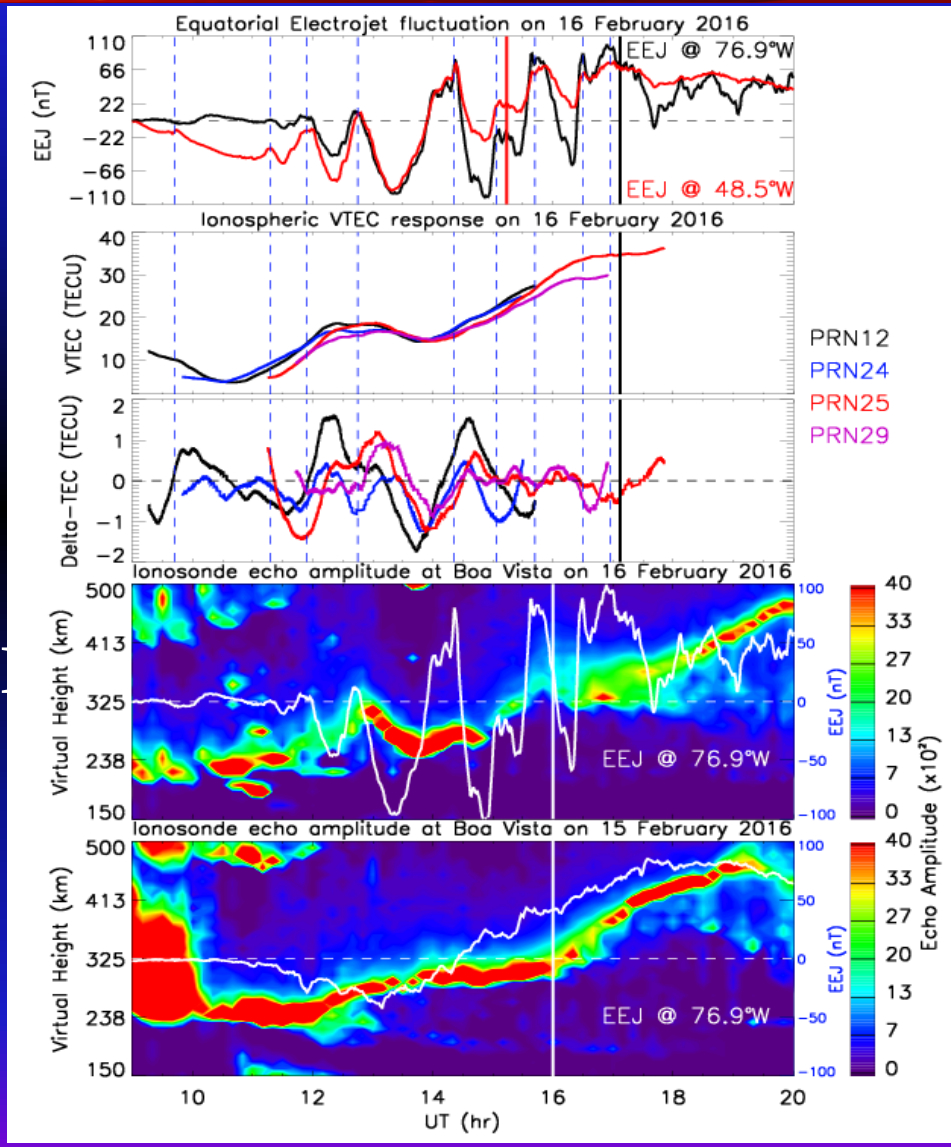
- **May causes density fluctuation of magnitude:**

$$\Delta N/N = 2\beta Vz/(2\pi f)^2 H_\beta$$

**$\Delta N$ (modulation in density), $\beta$ (recombination rate), $f$ (frequency of ULF wave), $H_\beta$ (recombination rate scale height).**

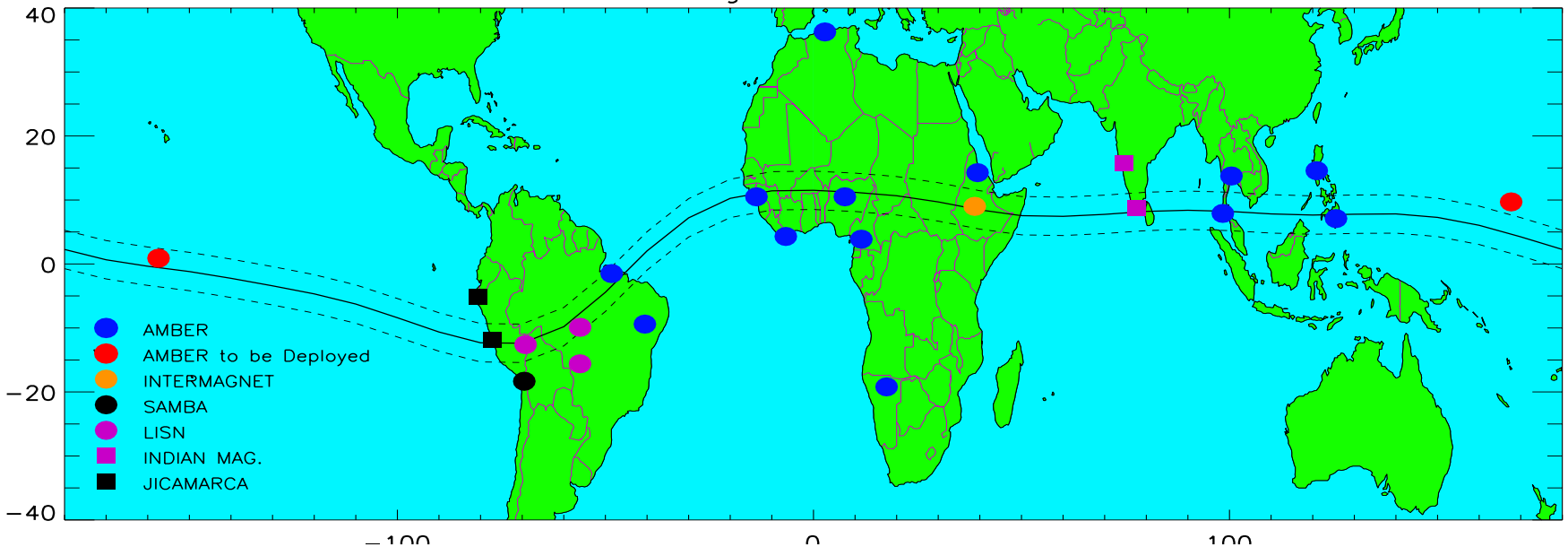
# Solar wind-magnetosphere-ionosphere coupling impact on equatorial ionosphere

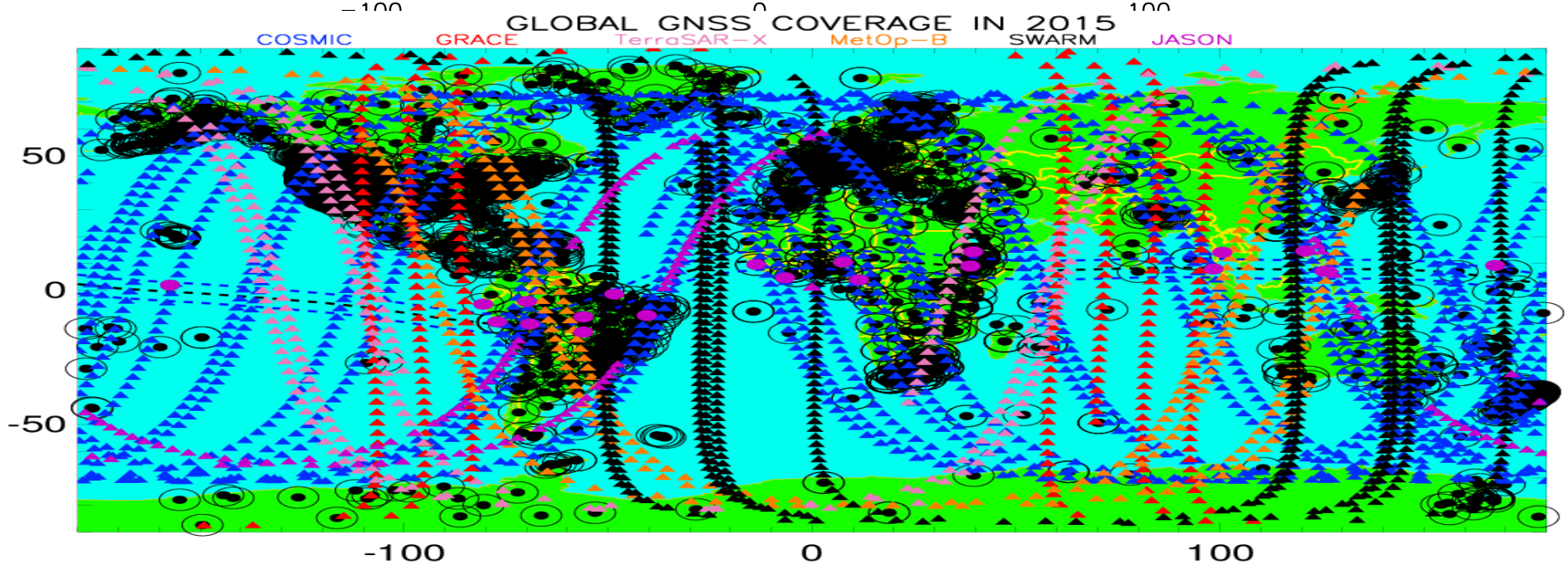



*Yizengaw et al., GRL, 2016*

# Future Task

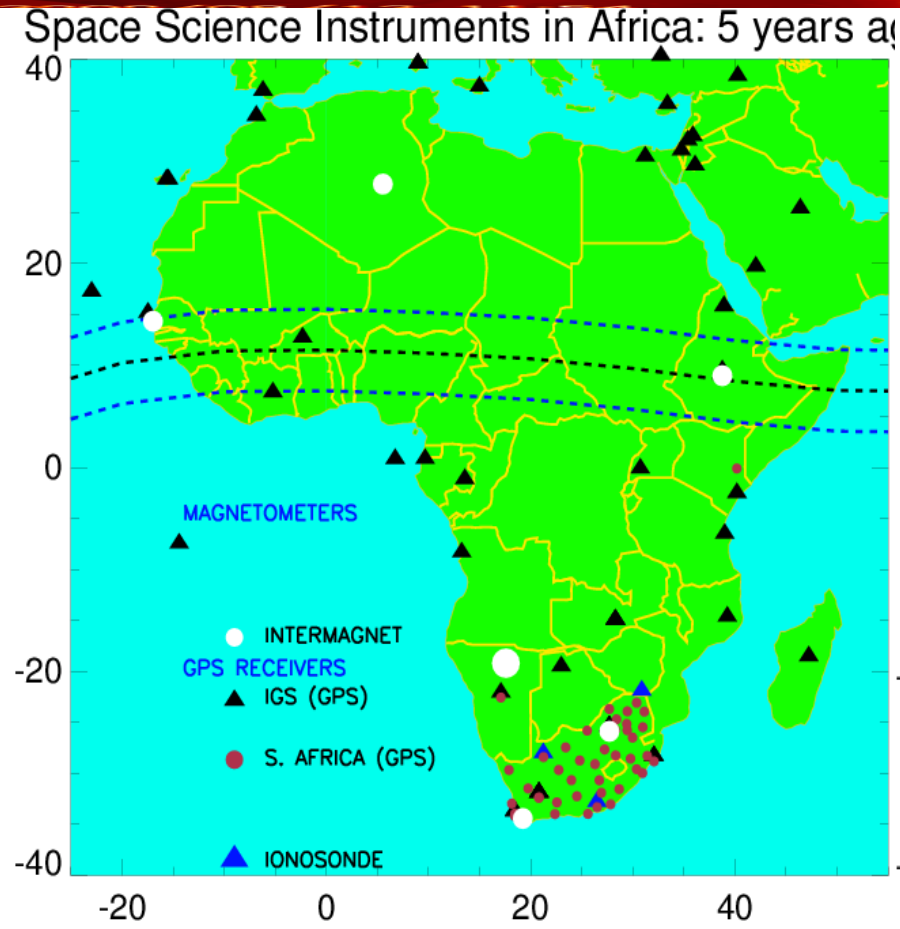

40
20
0
−20
−40
AMBER
AMBER to be Deployed
INTERMAGNET
SAMBA
LISN
INDIAN MAG.
JICAMARCA

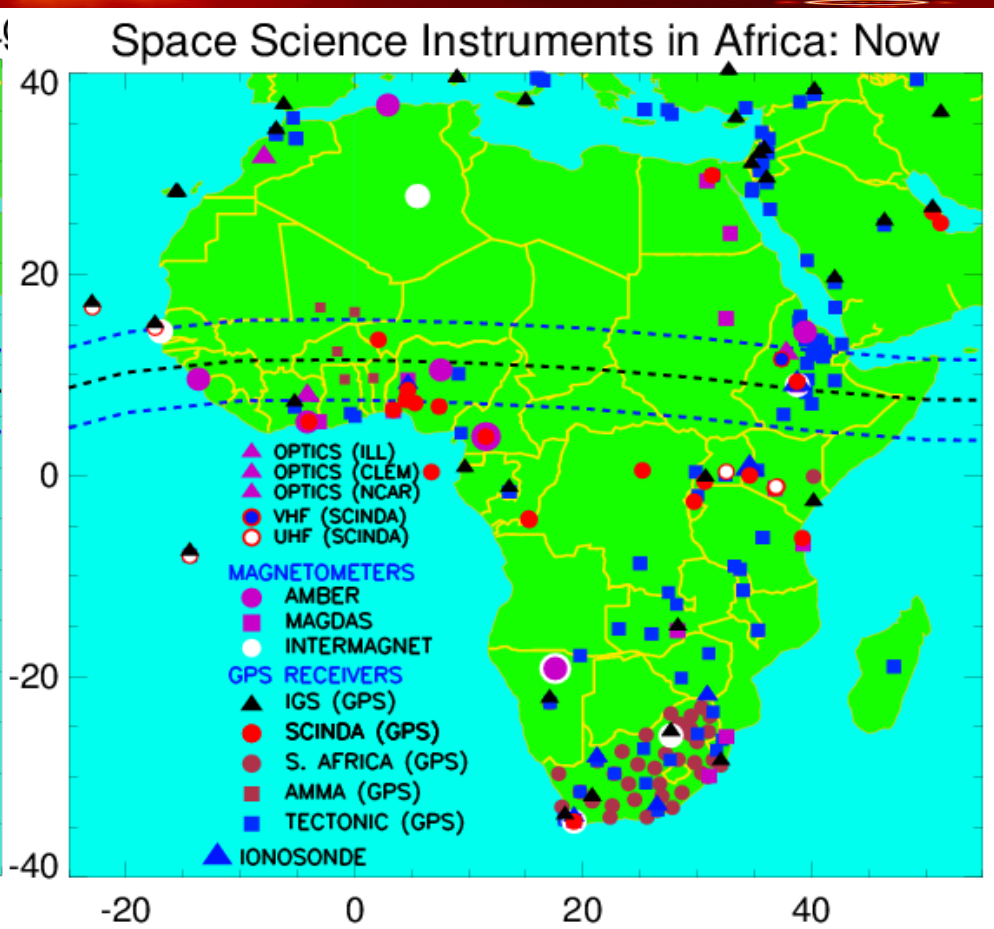

GLOBAL GNSS COVERAGE IN 2015
COSMIC
GRACE
TerraSAR−X
MetOp−B
SWARM
JASON
50
0
-50
-100
0
100

# Summary with Potential Questions

- **It is obvious that the ULF wave energy poured onto the ionosphere can significantly modulate the electrodynamics and cause density fluctuations.**
- **How often and under what solar wind conditions ULF waves penetrate to the equatorial ionosphere?**
- **when the *FACs* are in continuous dynamic, they form significantly fluctuating *DP*2 current systems that can easily penetrate to the equatorial region and modulate the dayside equatorial electrodynamics and thus ionospheric density.**

# General Instrumentation in Africa

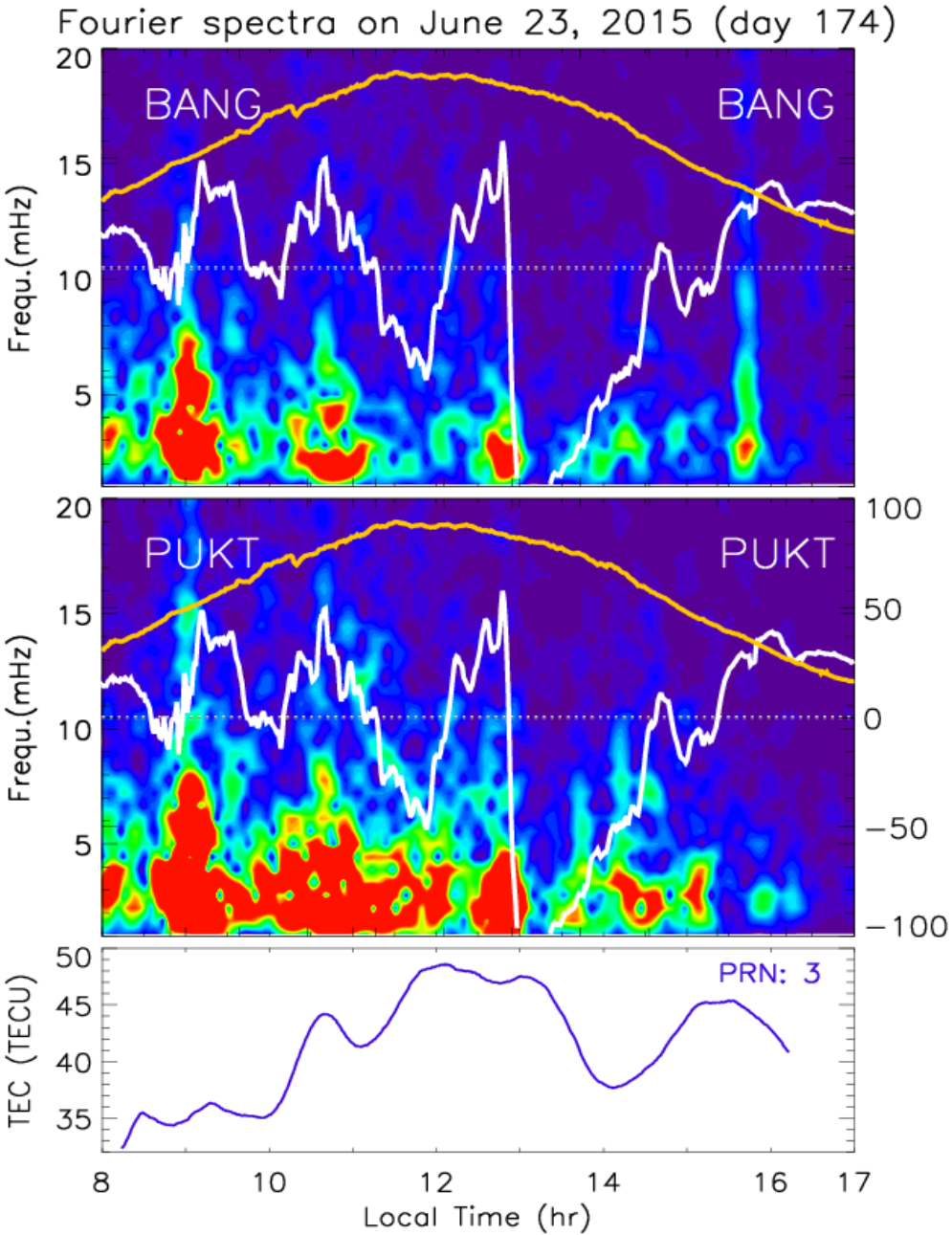


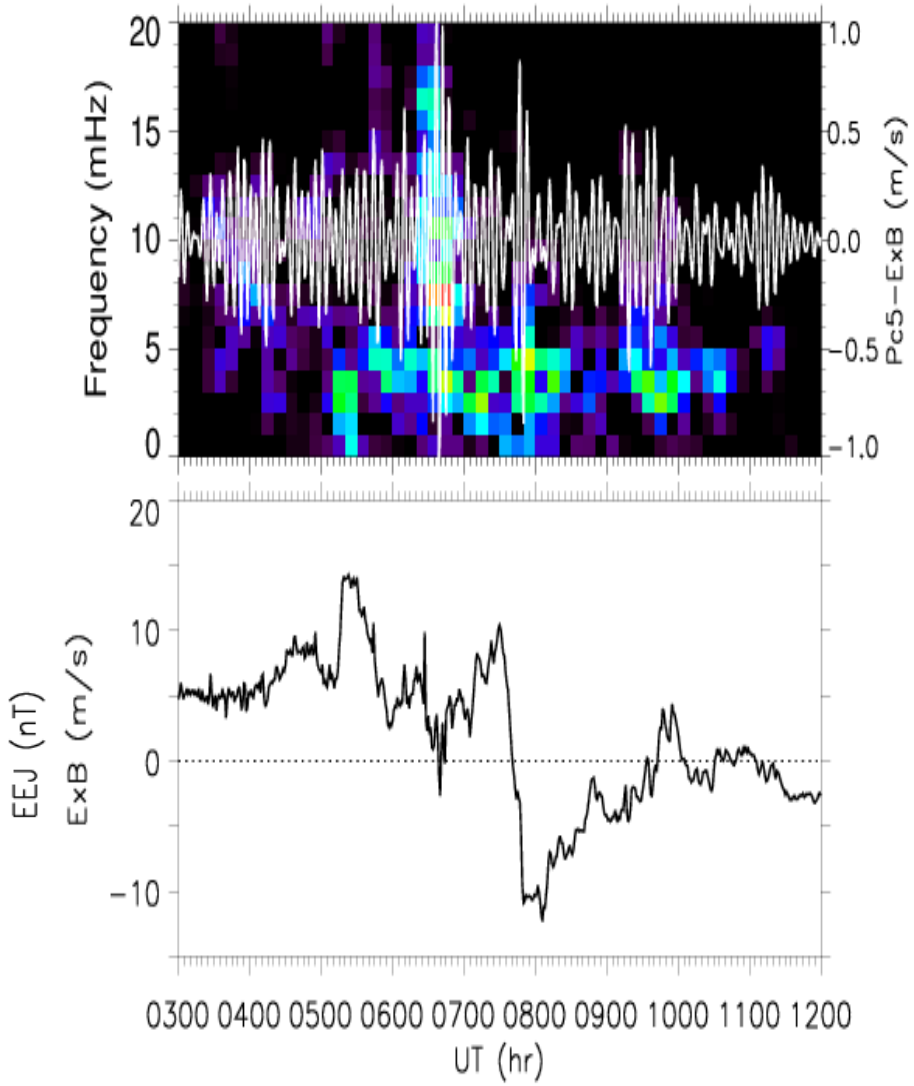




**Eight Years ago** **This Now!**

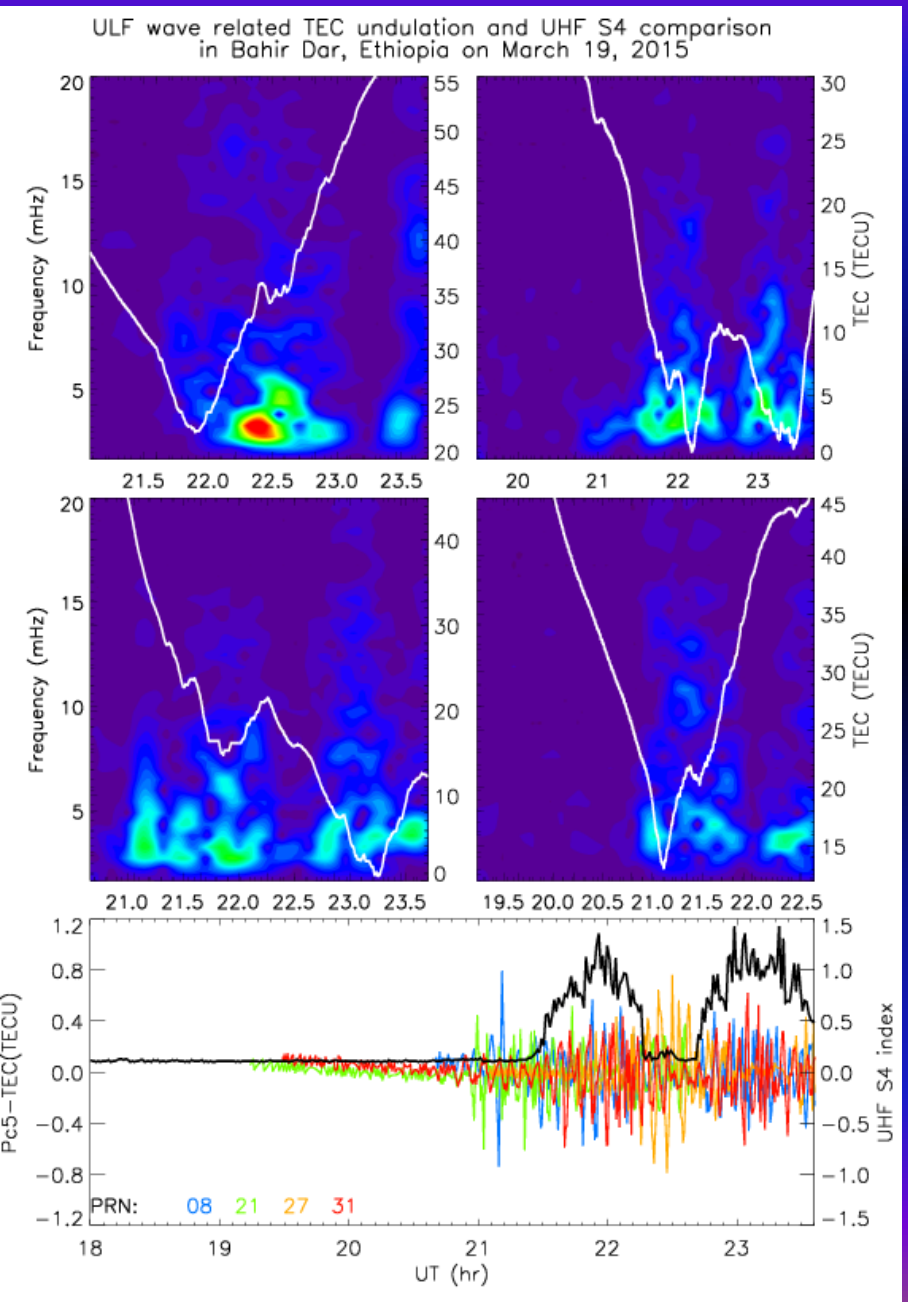
# Thank you!

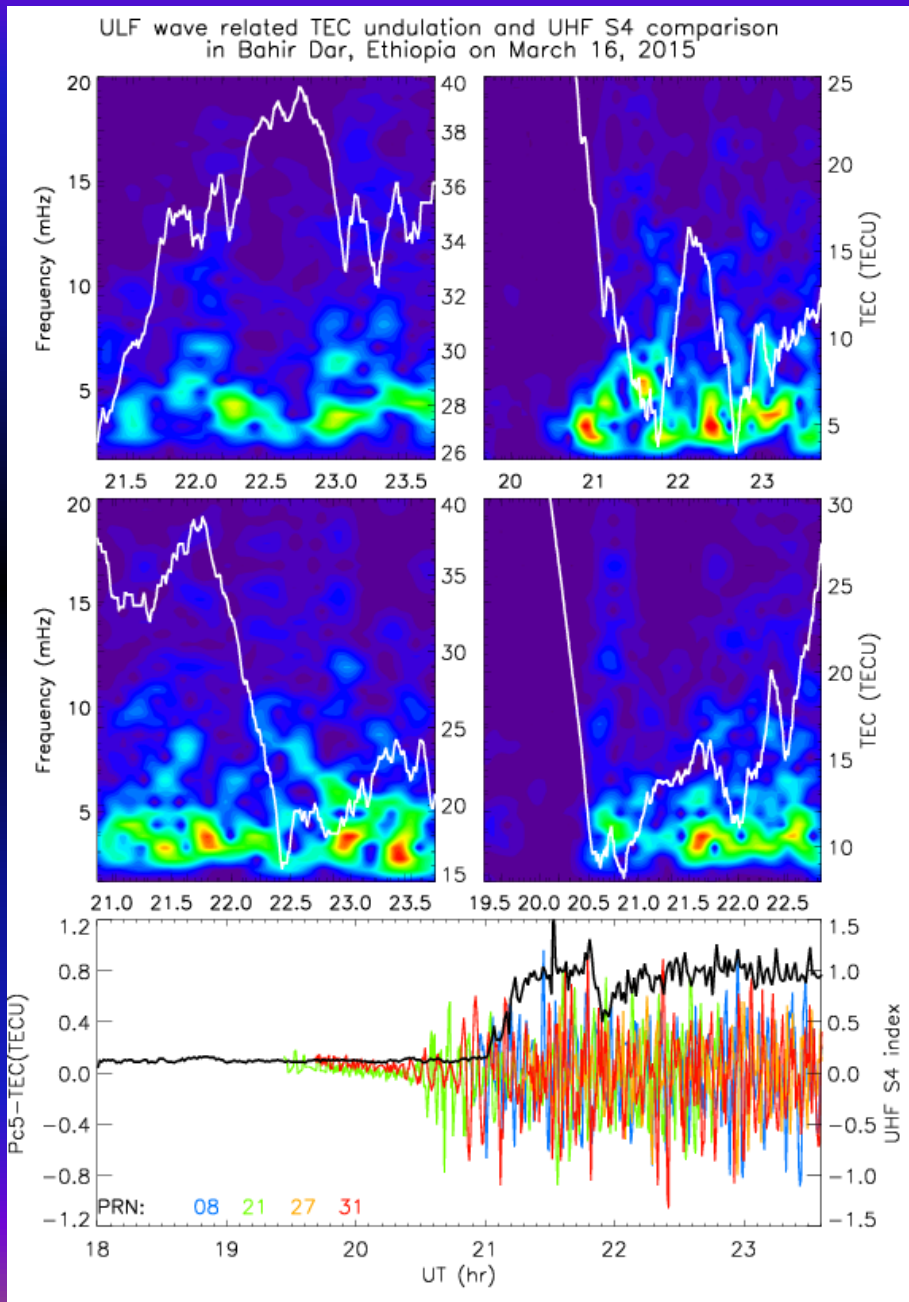
# What is the possible mechanisms?

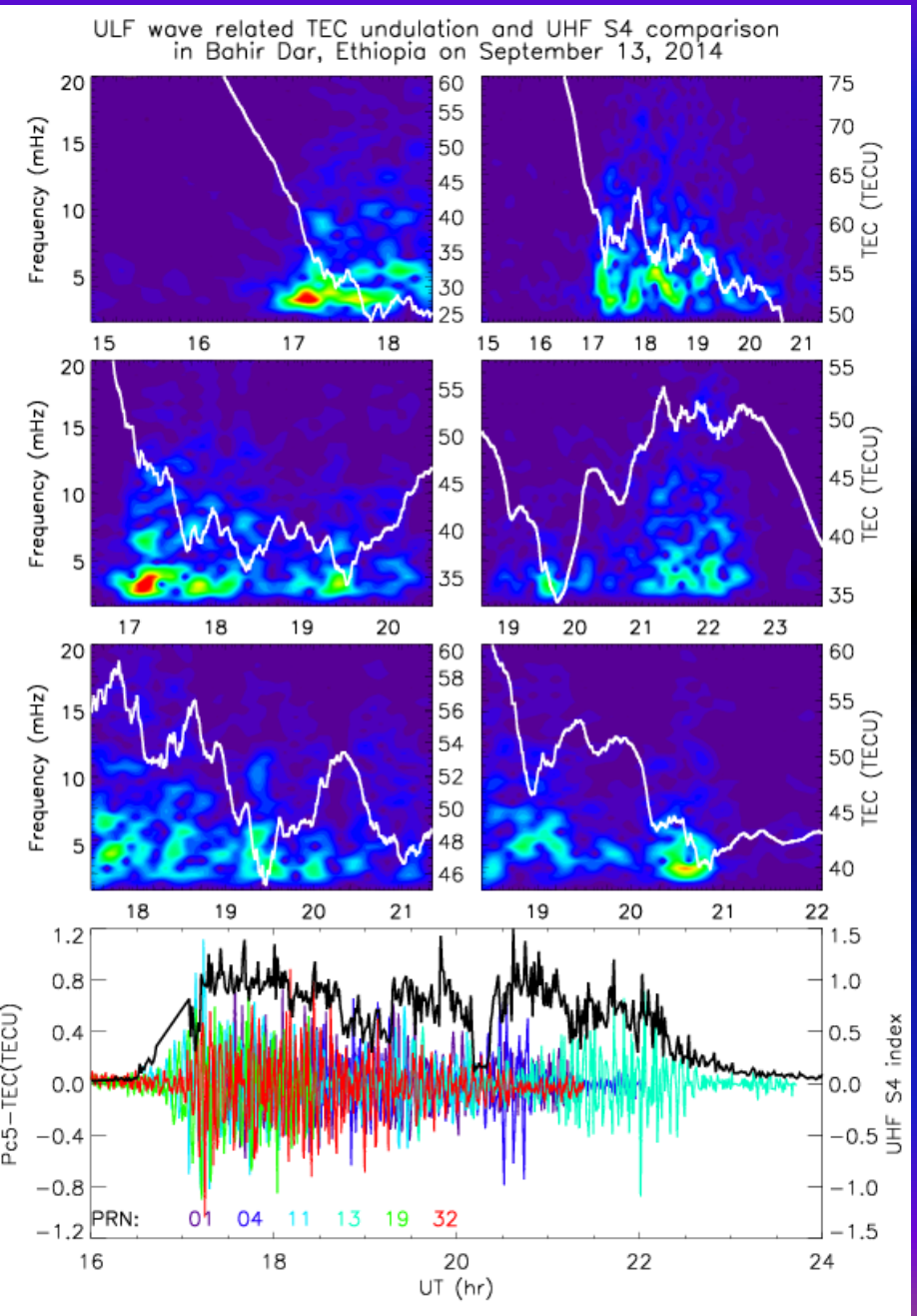


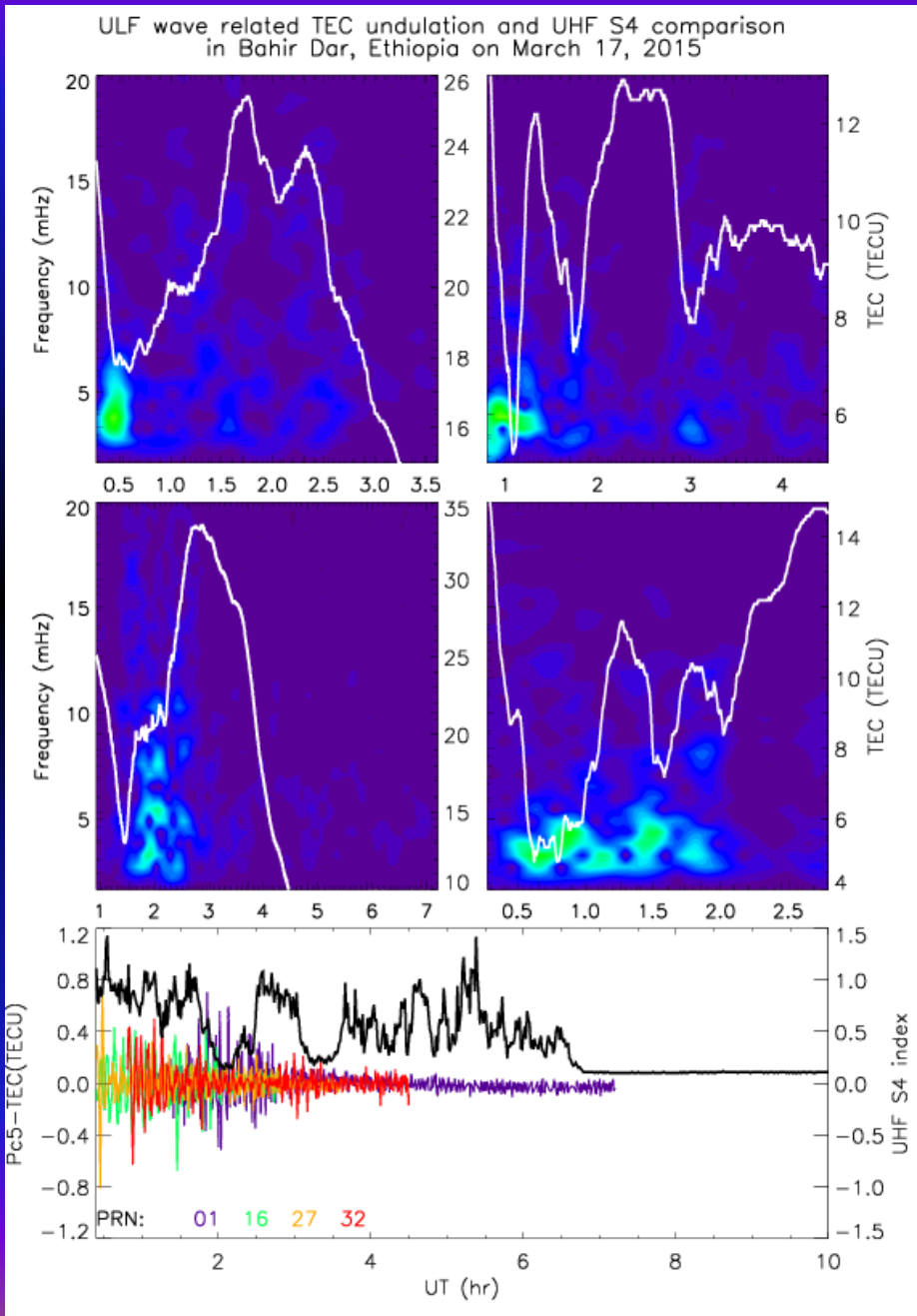



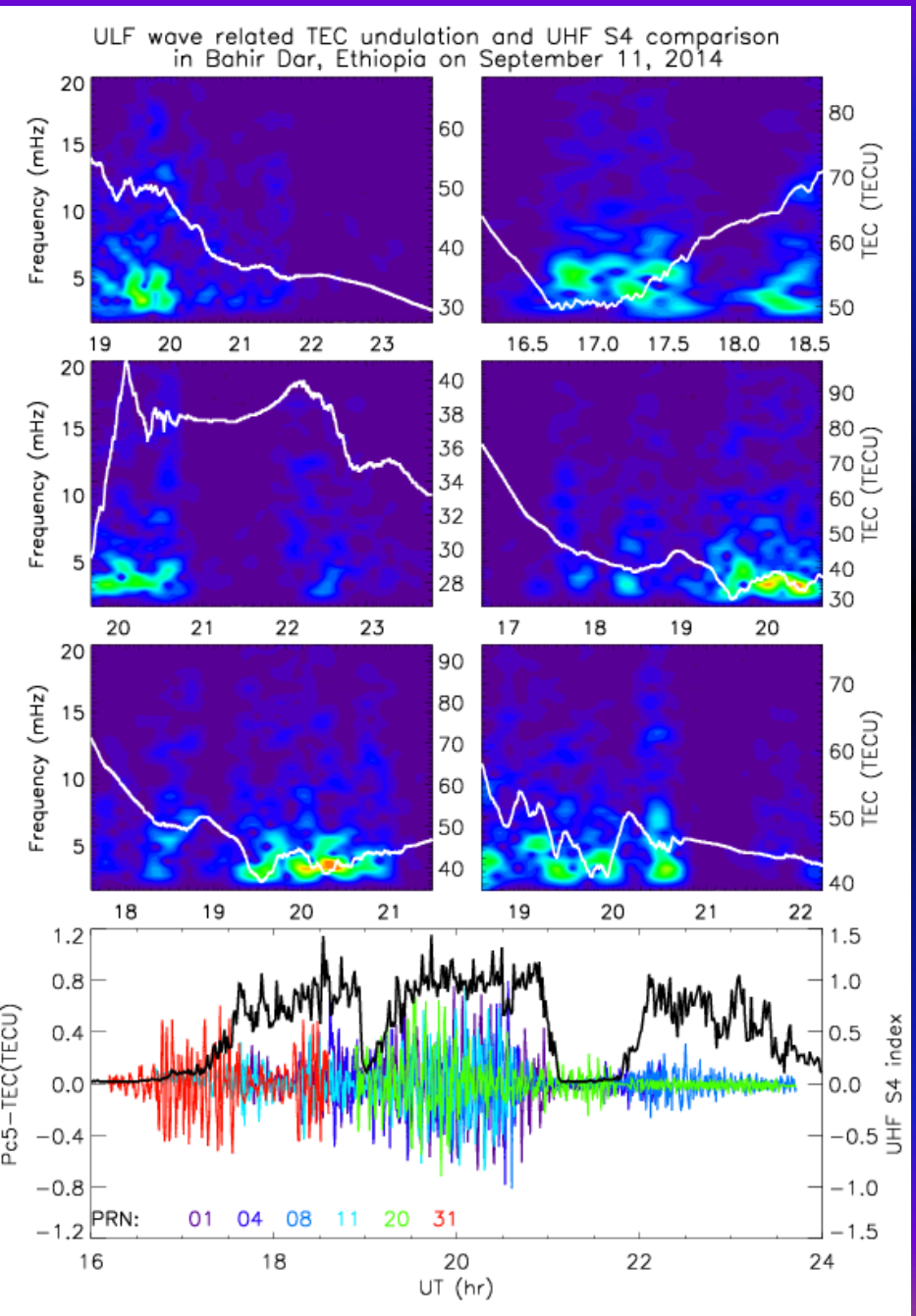

*Yizengaw et al., 2013*


ULF wave related TEC undulation and UHF S4 comparison
in Bahir Dar, Ethiopia on March 19, 2015
Frequency (mHz)
TEC (TECU)
Pc5-TEC(TECU)
UHF S4 index
PRN: 08 21 27 31
UT (hr)

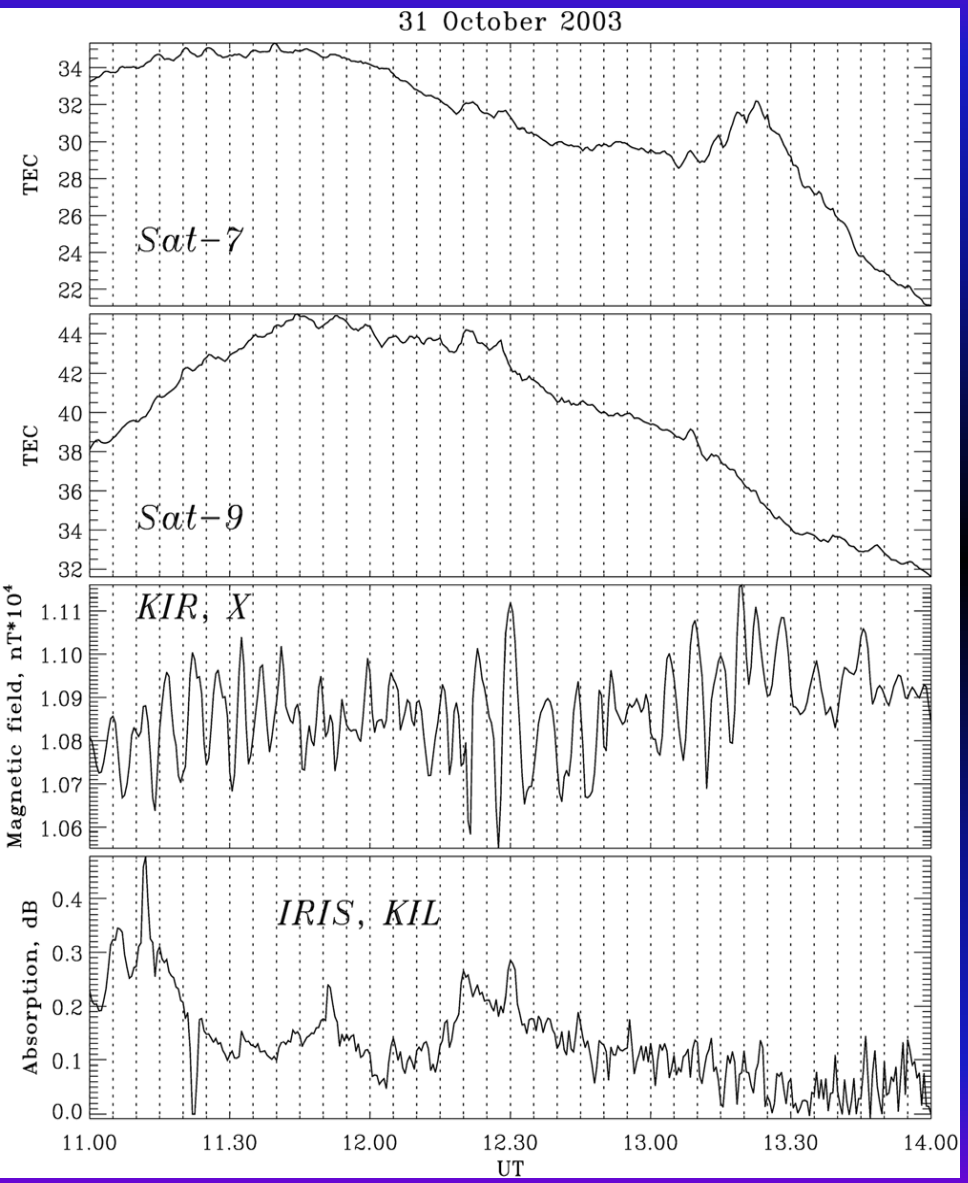

ULF wave related TEC undulation and UHF S4 comparison
in Bahir Dar, Ethiopia on March 16, 2015
Frequency (mHz)
TEC (TECU)
Pc5-TEC(TECU)
UHF S4 index
PRN: 08 21 27 31
UT (hr)

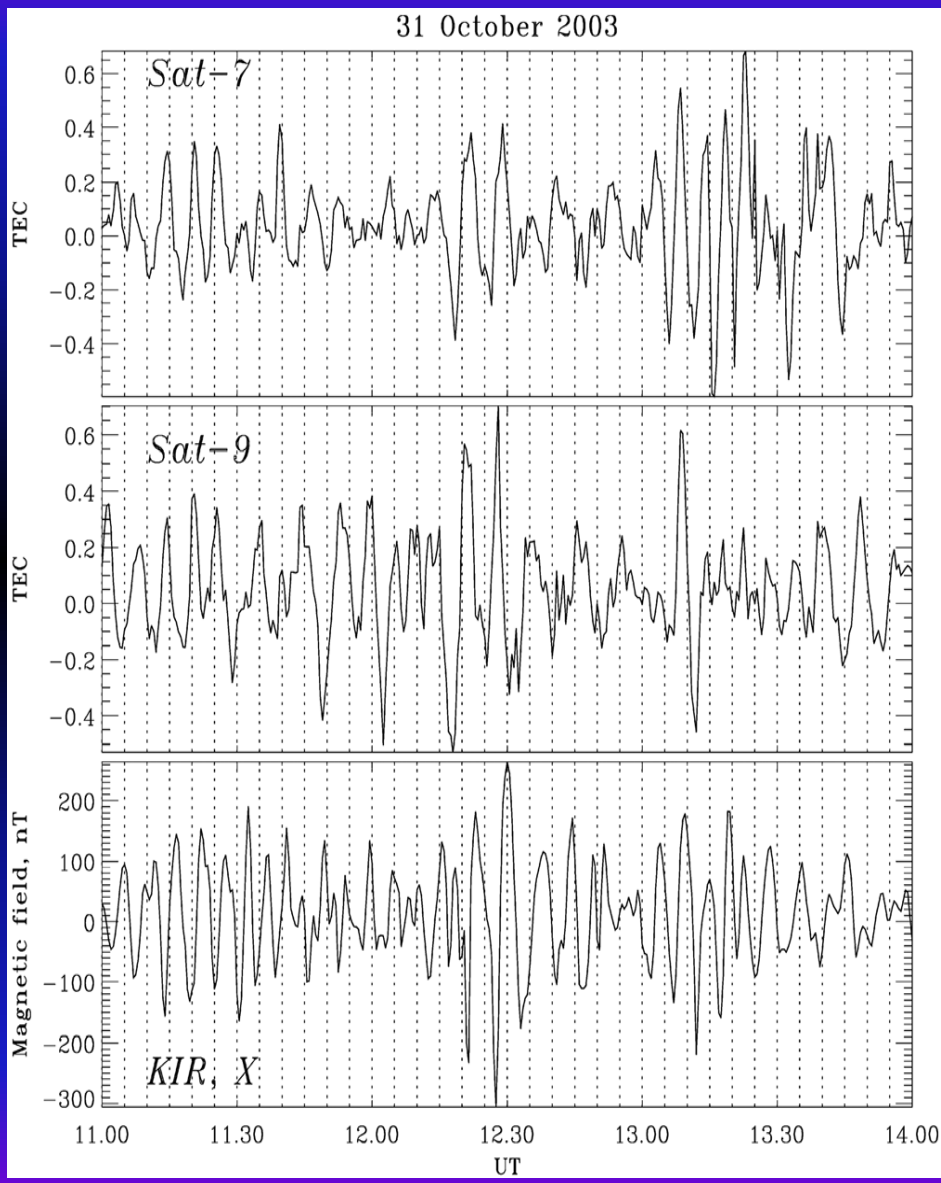

ULF wave related TEC undulation and UHF S4 comparison
in Bahir Dar, Ethiopia on September 13, 2014
Frequency (mHz)
TEC (TECU)
Pc5-TEC(TECU)
UHF S4 index
PRN: 01 04 11 13 19 32
UT (hr)


ULF wave related TEC undulation and UHF S4 comparison
in Bahir Dar, Ethiopia on March 17, 2015
Frequency (mHz)
TEC (TECU)
Pc5-TEC(TECU)
UHF S4 index
PRN: 01 16 27 32
UT (hr)


ULF wave related TEC undulation and UHF S4 comparison
in Bahir Dar, Ethiopia on September 11, 2014
Frequency (mHz)
TEC (TECU)
Pc5−TEC(TECU)
UHF S4 index
PRN: 01 04 08 11 20 31
UT (hr)

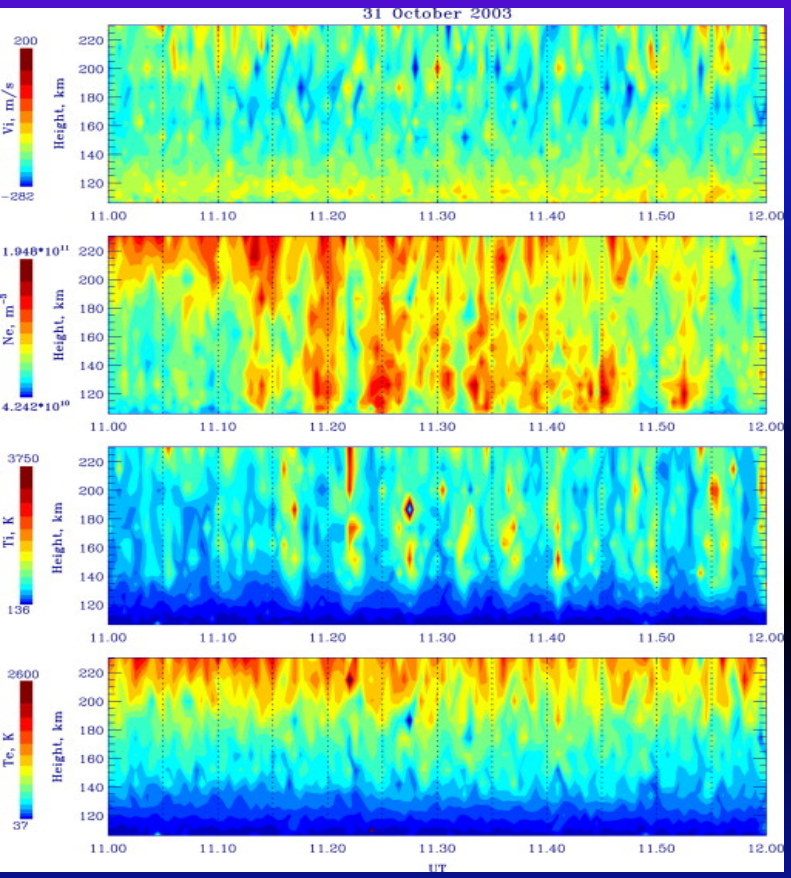
# TEC modulation by ULF waves




*Pilipenko et al., JGR, 2014*

# Other ULF wave modulate mechanism




*Pilipenko et al., JASTP, 2014*

**Through ion heating: dominant mechanisms at high latitude region**

**At high latitude For example; any typical Pc5 wave of *f* = *3mHz at* *Δβ=0.1mHz→* *ΔTi=300K,* may cause *ΔN/N* ~ 0.8% fluctuation (*Pilipenko et al., JGR, 2014).***

**This has been demonstrated by radar community that Pc5 waves can modulate the ionospheric E-field, field-aligned current, density, and ionosphere conductance (*Reddy et al., AG, 1994; Pilipenko et al., JASTP, 2014).***

# iMAGs (SAMBA-AMBER-MEASURE)

**Team Members:** M. Moldwin (UM); E. Yizengaw (BC); E. Zesta (NASA); A. Boudouridis (SSI); M. Magoun (BC); K. Hector (UCLA)