

# *Earthquakes & Tsunamis flirting with the Ionosphere ...take a ride to Venus !!*

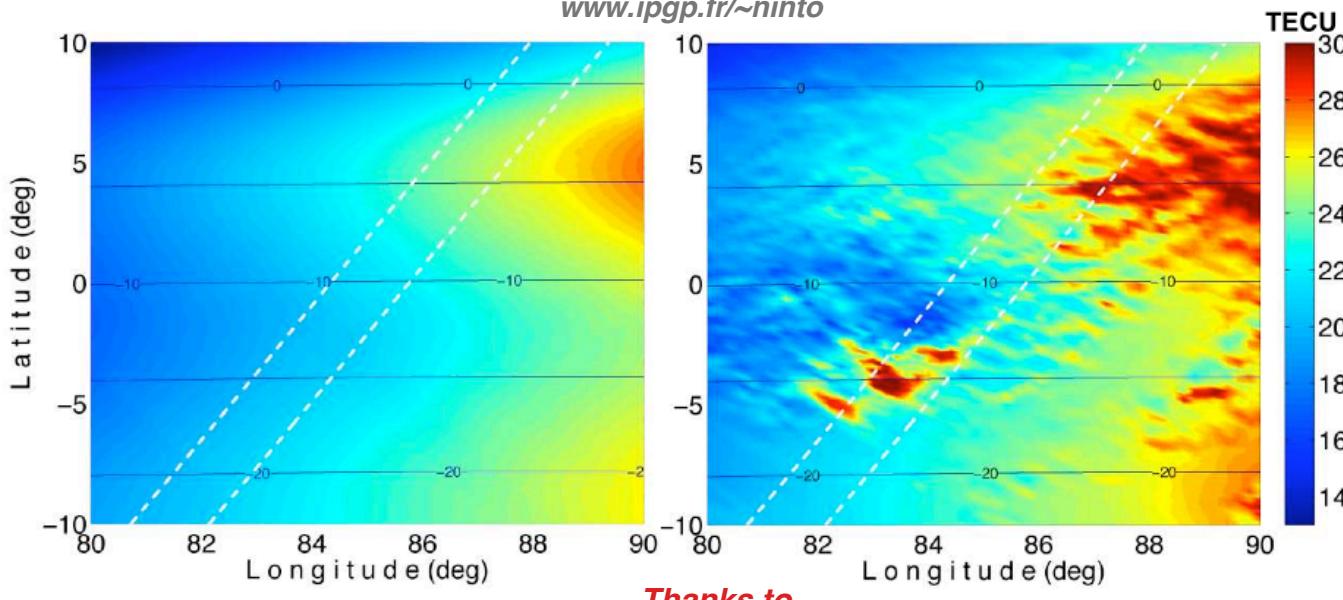
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*Institut de Physique du Globe de Paris*

*Université Paris Diderot*

*Contact: ninto@ipgp.fr*

*www.ipgp.fr/~ninto*



*Thanks to*

*T. Harmel (Obs. Villefranche), L. Rolland (IPGP),*

*E. Alam Kherani (???), H. Hébert (CEA), F. Crespon (NOVELTIS), R. Garcia and P. Lognonné (IPGP)  
as well as*

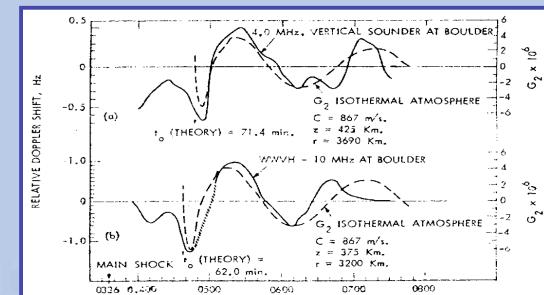
*T. Farge (CEA) for Doppler data, J.-P. Avouac (Caltech) and C. Vigny (ENS) for GPS data*



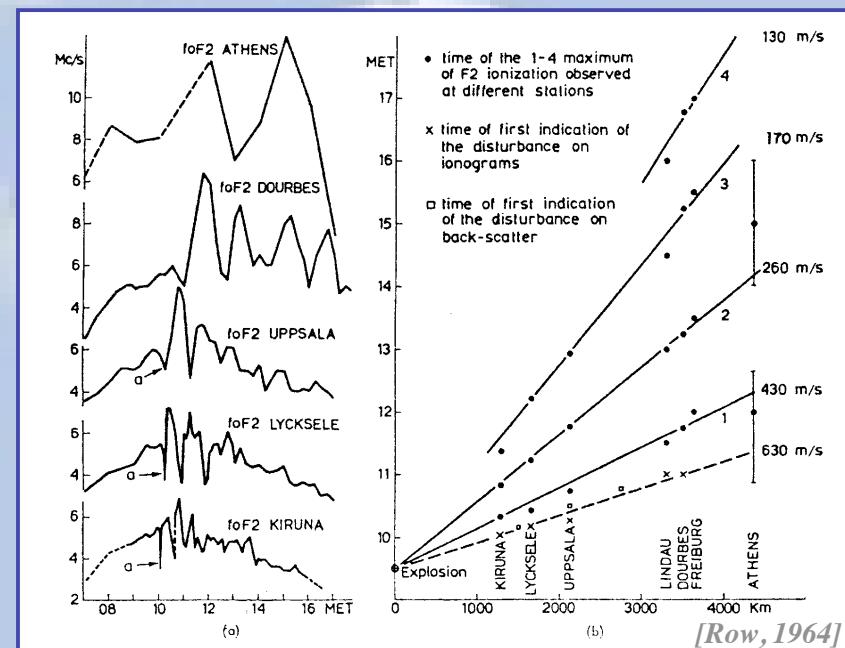
*The winds, heated by the Sun,  
are the causes of Earthquakes !!*

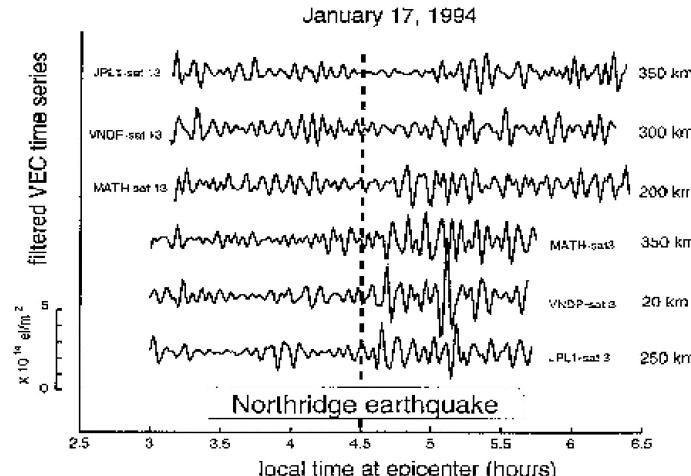
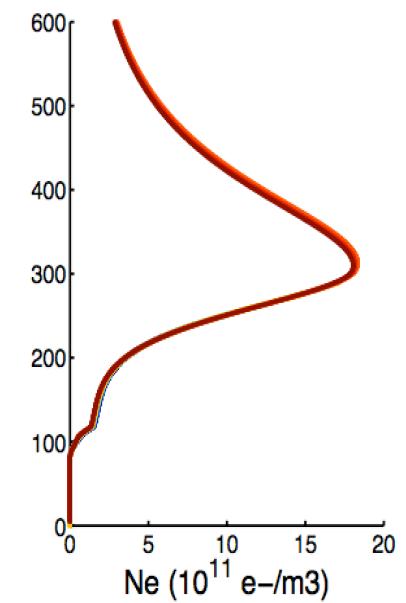
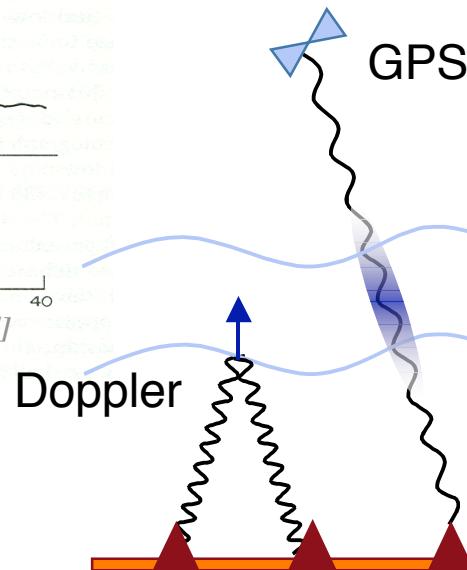
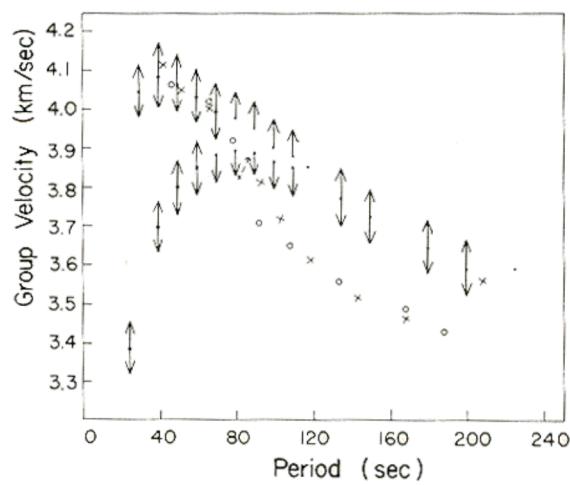
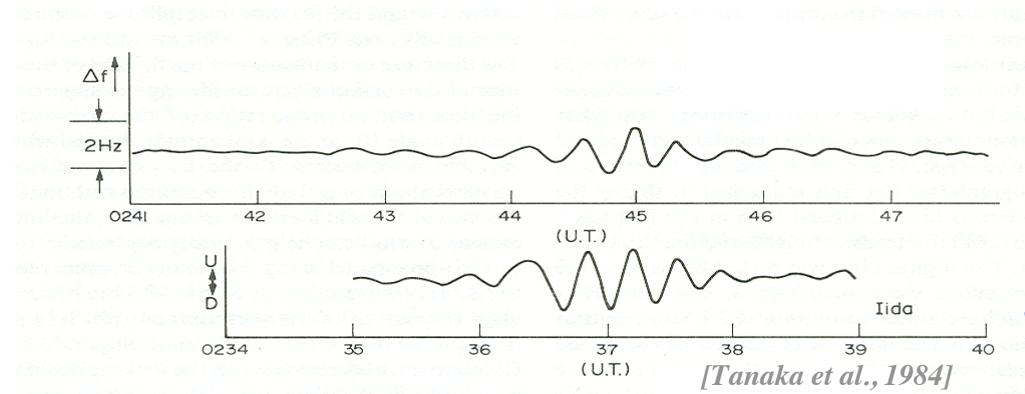


*Earthquake*

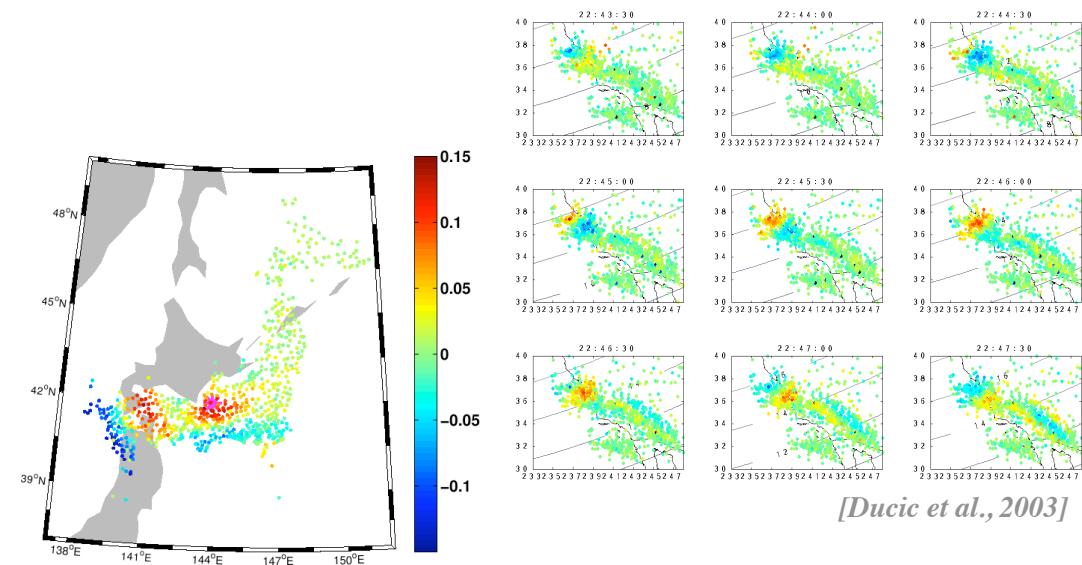
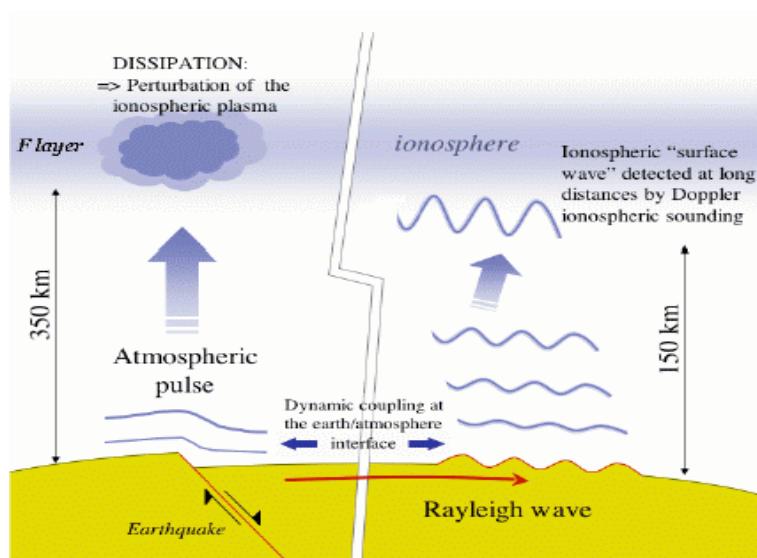
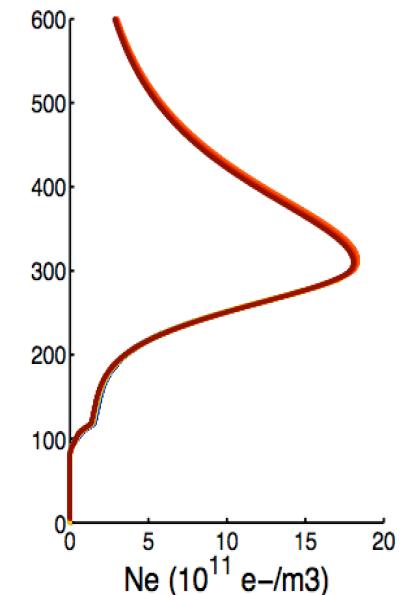
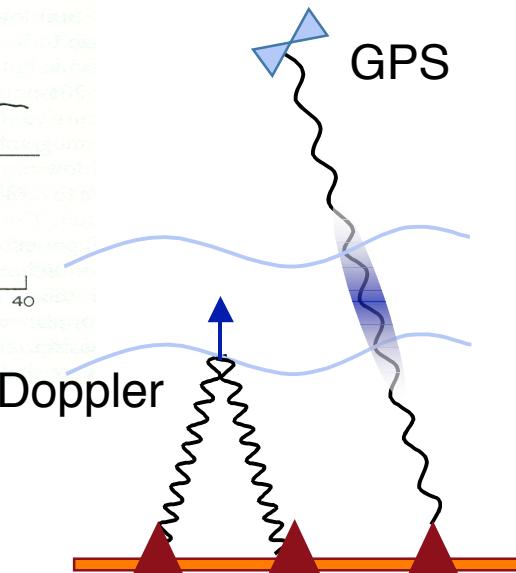
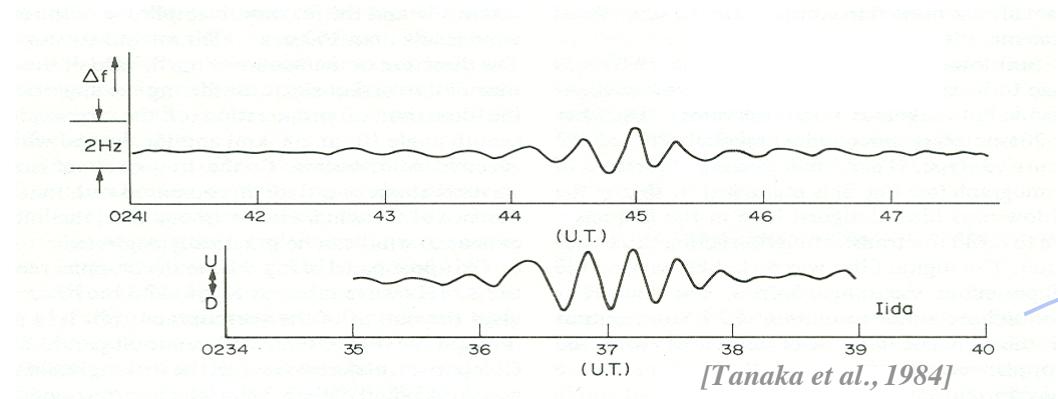


*Nuclear Explosion*

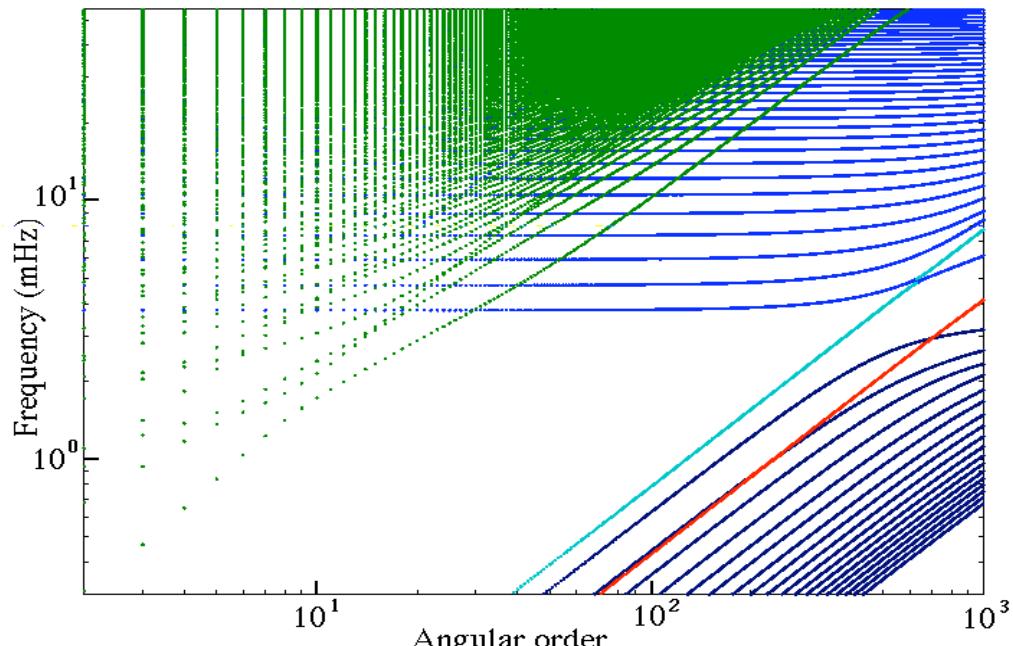




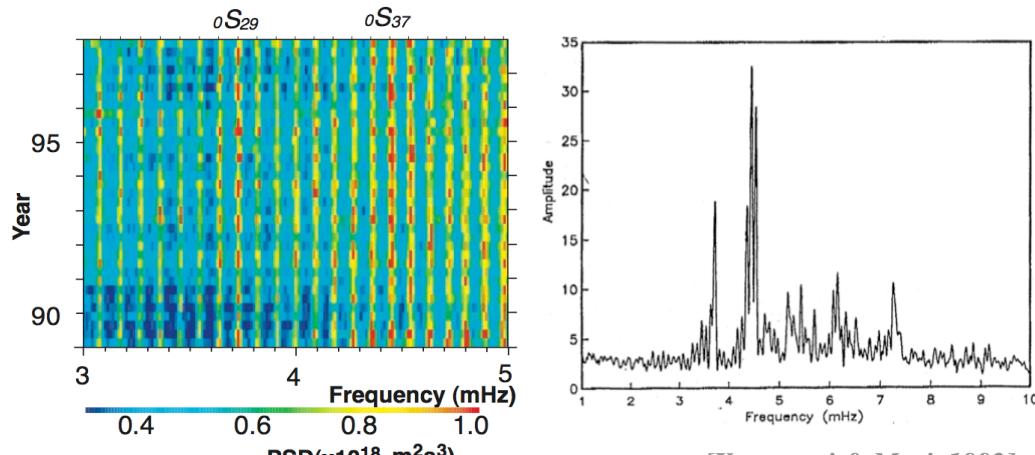
[Calais & Minster, 1995]



[Roland et al., under submission]



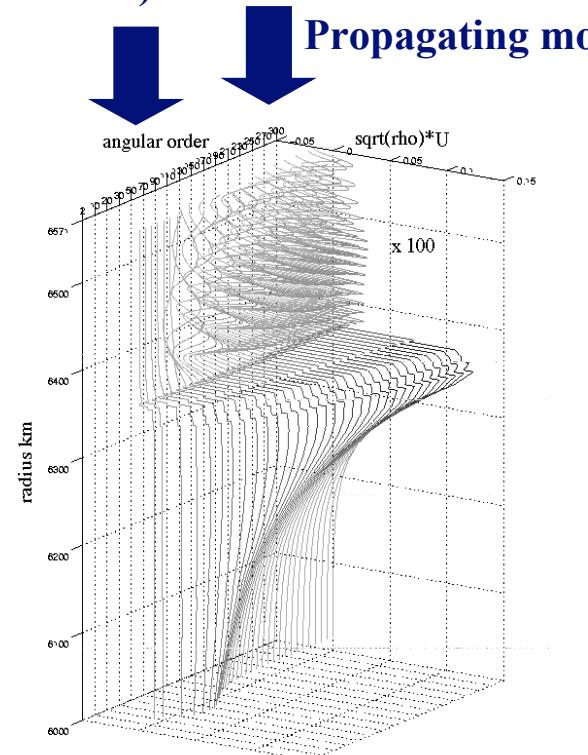
[Lognonné & Clevédé, 2002]



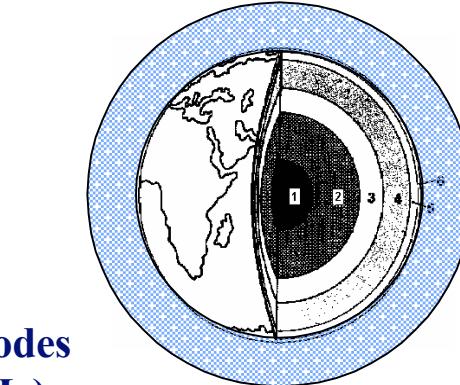
[Nishida et al., 2000]

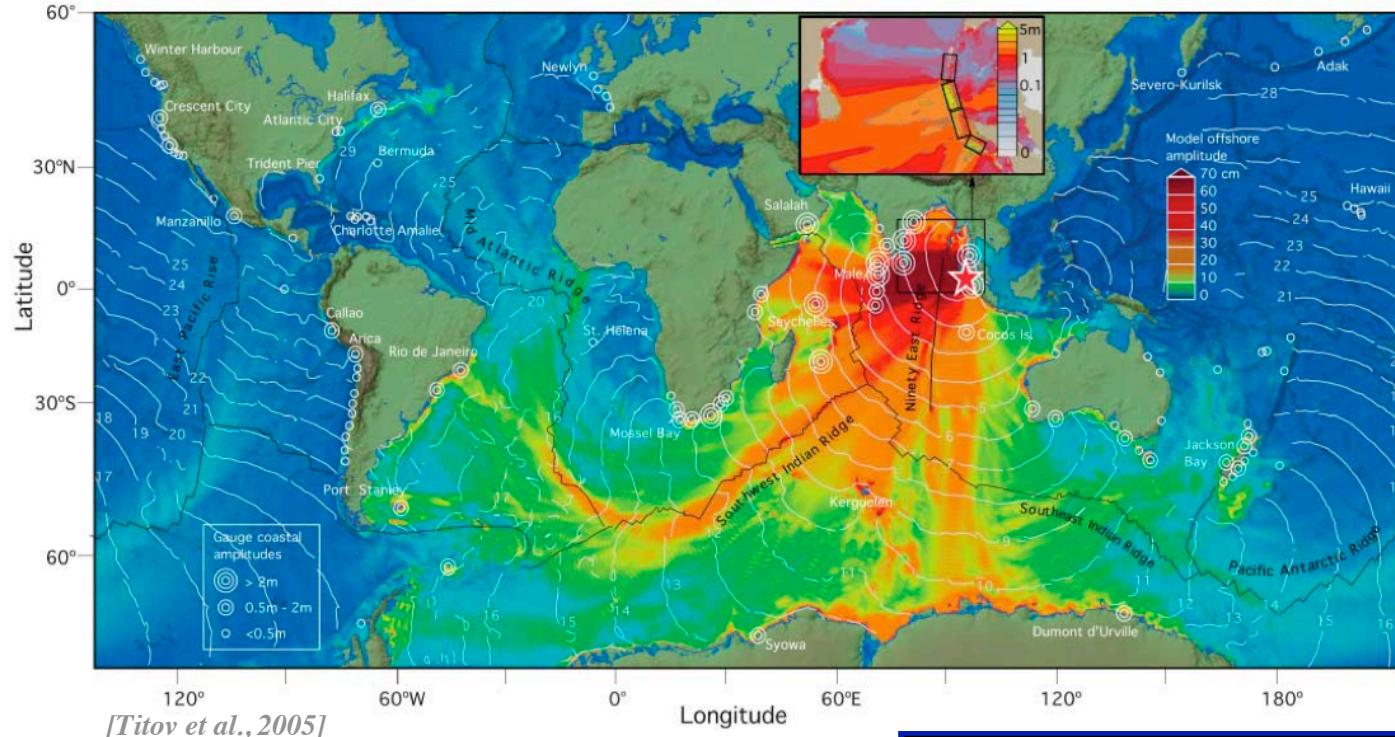
**Trapped modes**  
( $f \leq 3.68$  mHz)

**Propagating modes**



**Spheroidal modes  $n=0, l=2-300$**



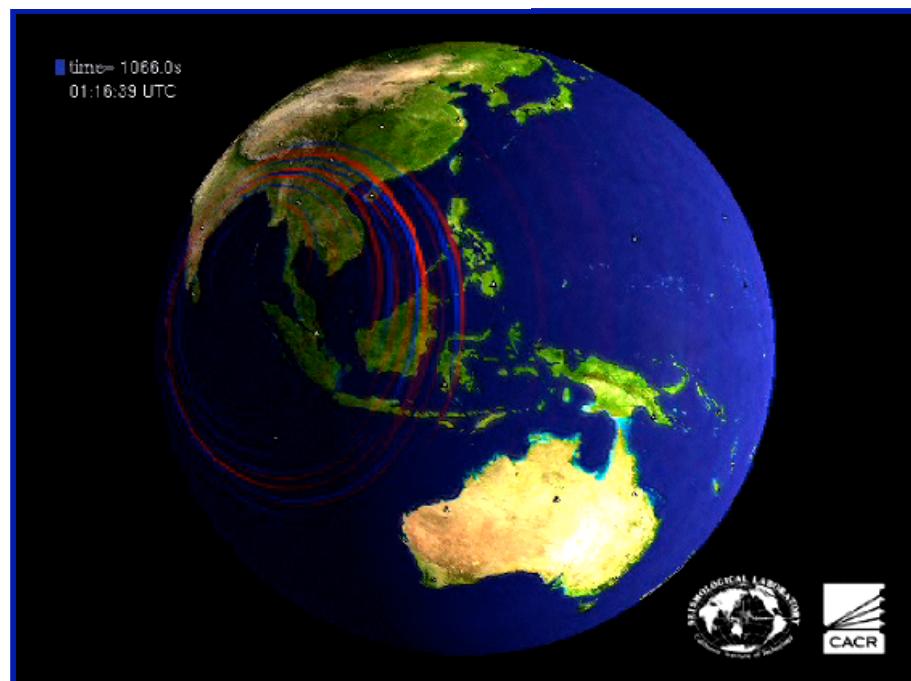


$M_t = 9.1$

[Ammon et al., 2006]

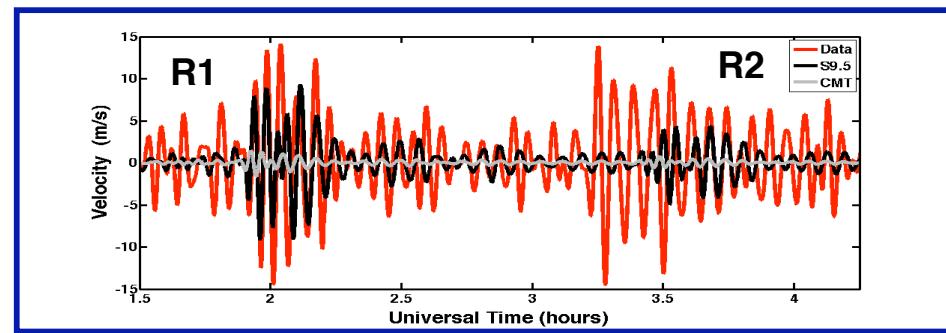
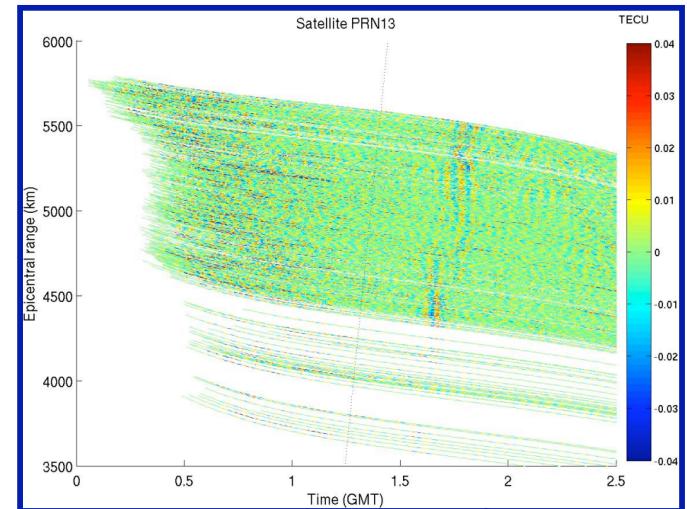
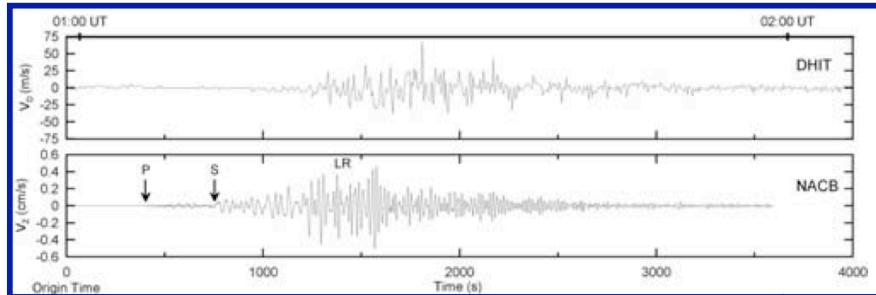
December 26, 2004

$M_w = 9.3$



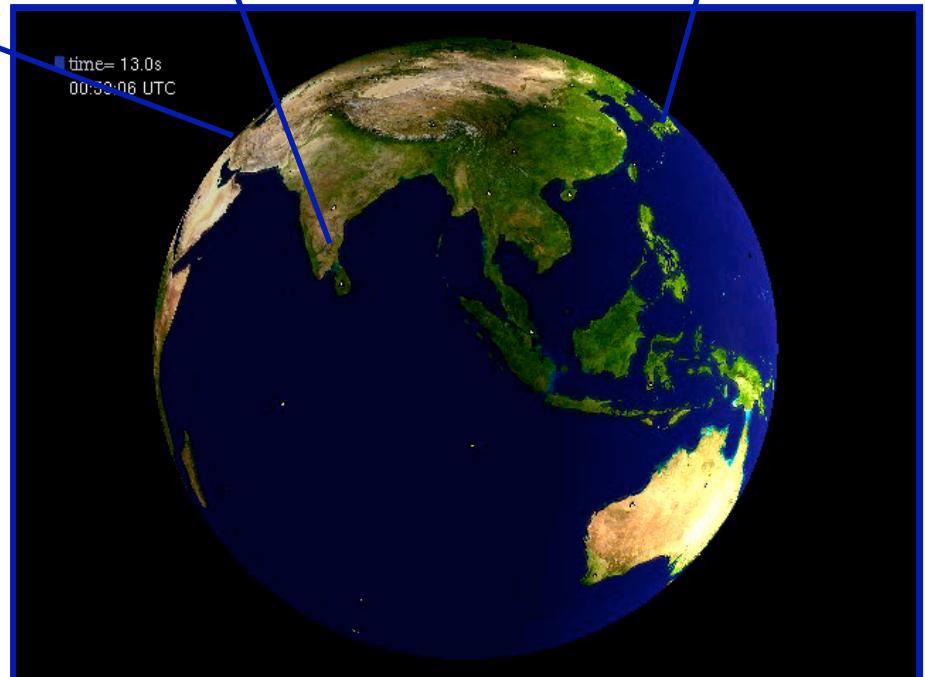
[Liu et al., 2006a]

[Crespon, 2007]



- Doppler sounding Data
- Modelling by normal modes summation following [Lognonné et al., 1998]

[Ammon et al., 2006]

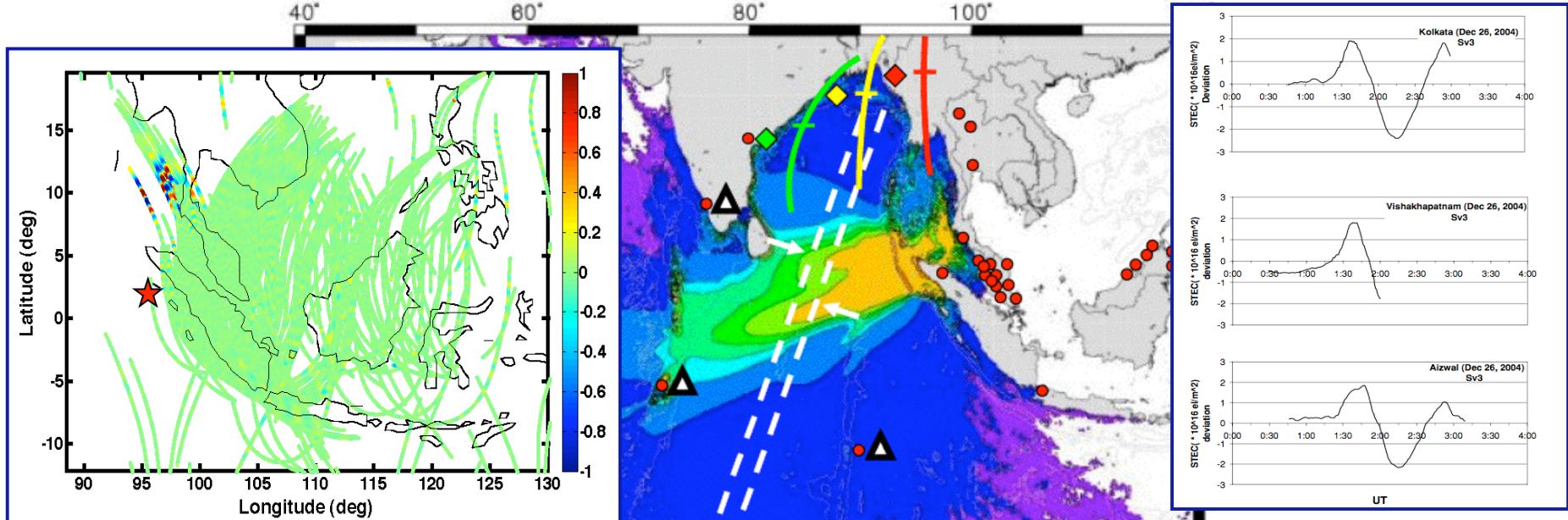


December 26, 2004

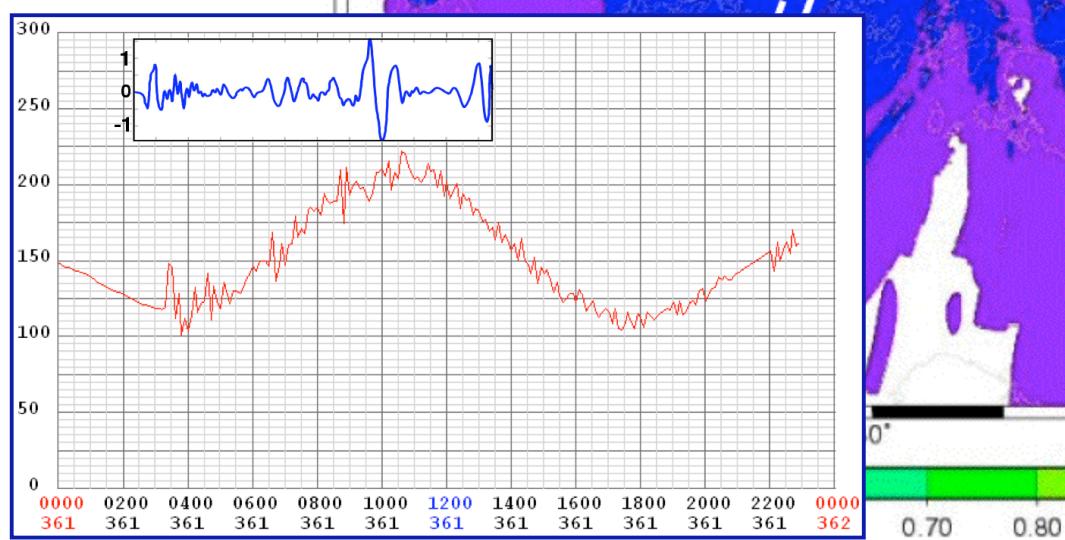
$$M_{\odot} = 9.3$$

# Tsunamigenic TEC perturbation by GPS

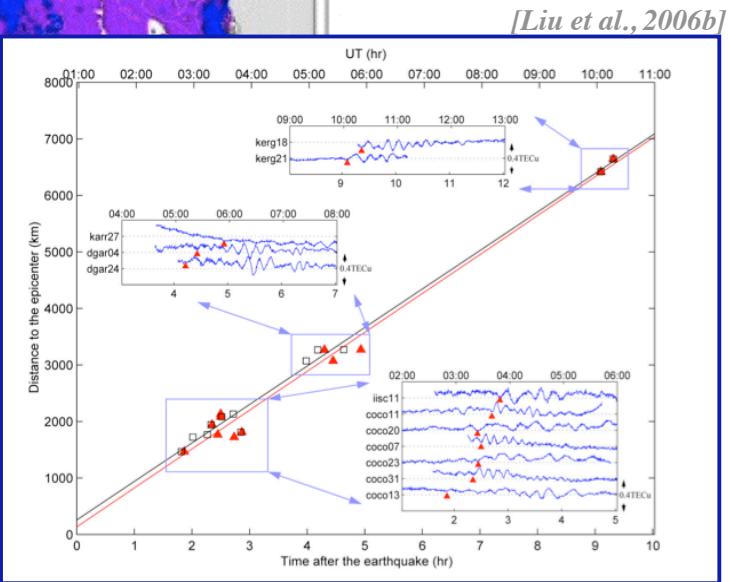
[DasGupta et al., 2006]



[Ocipinti et al., JGR, Under Submission]

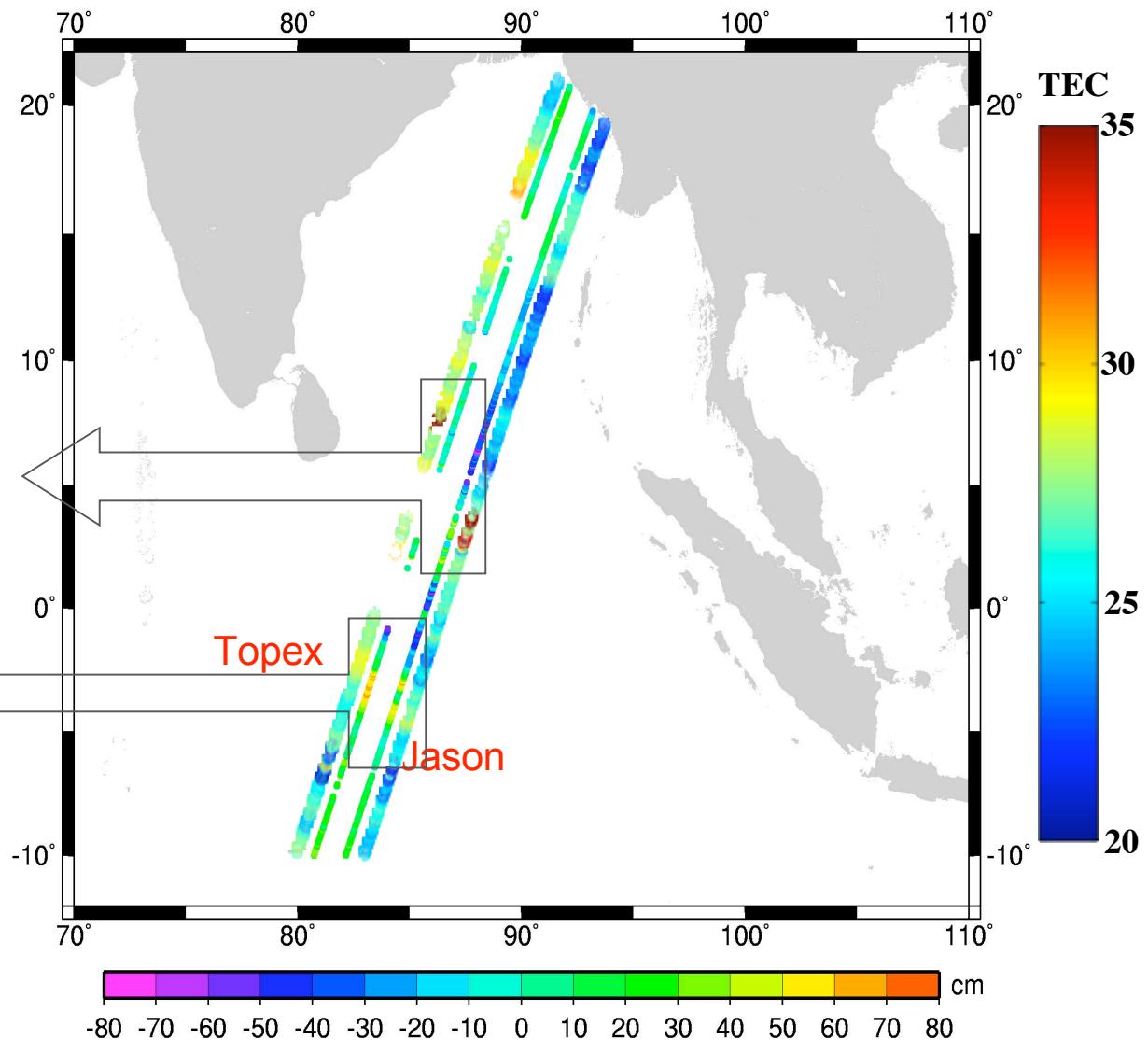


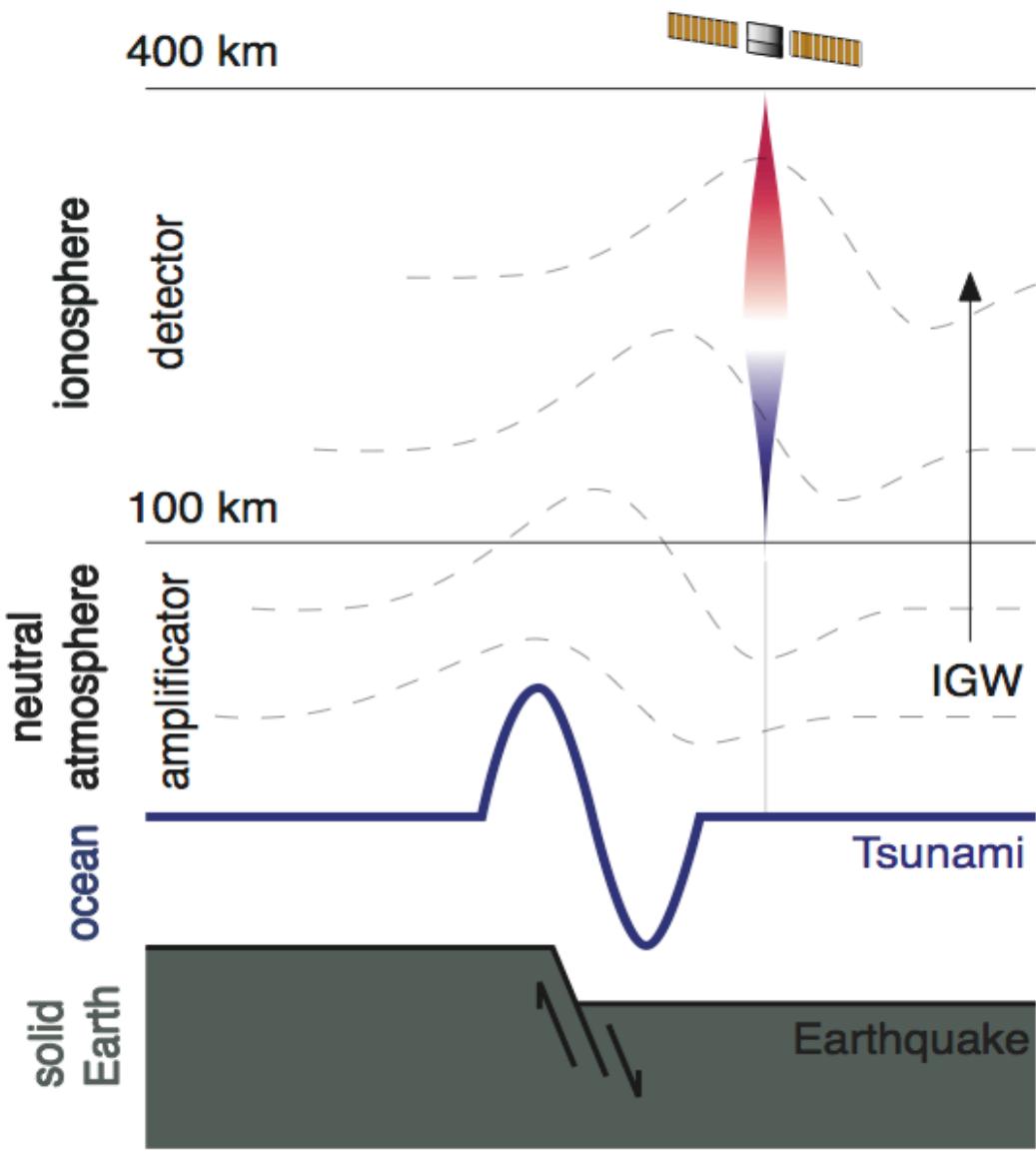
[Occhipinti et al., GPS World, 2008]



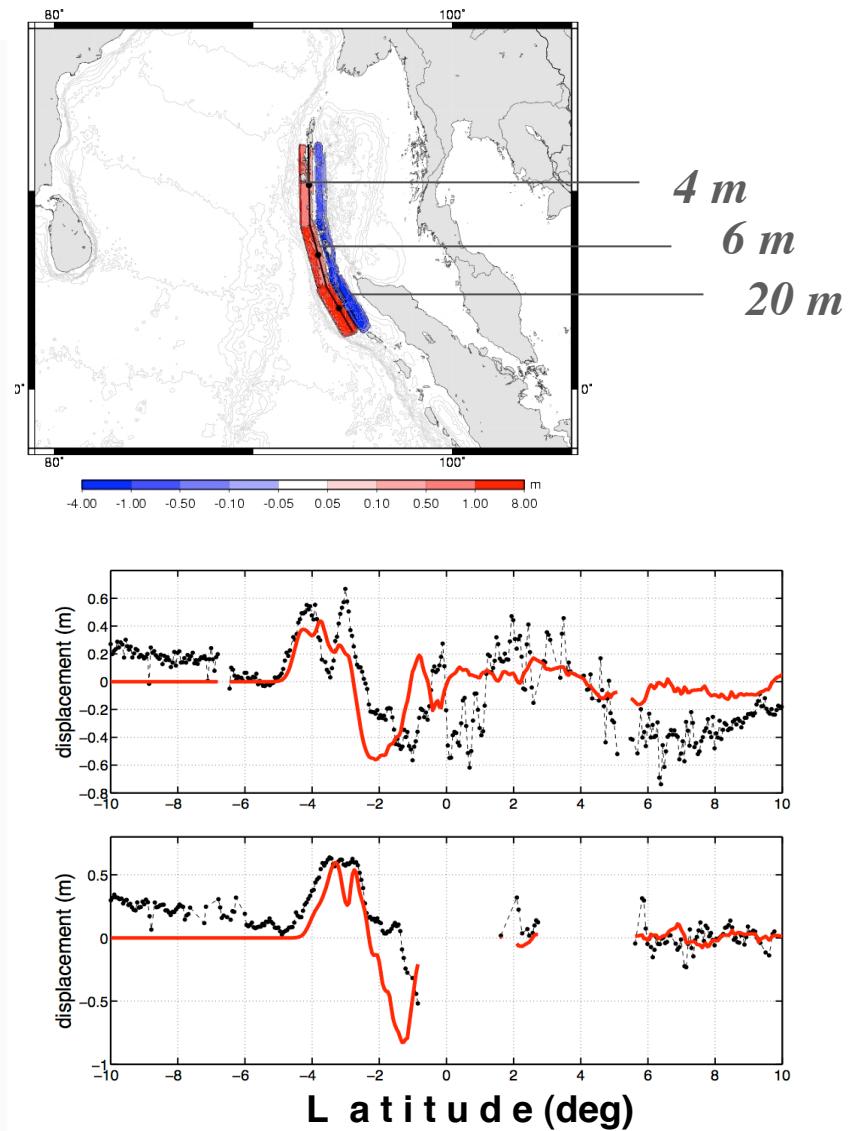
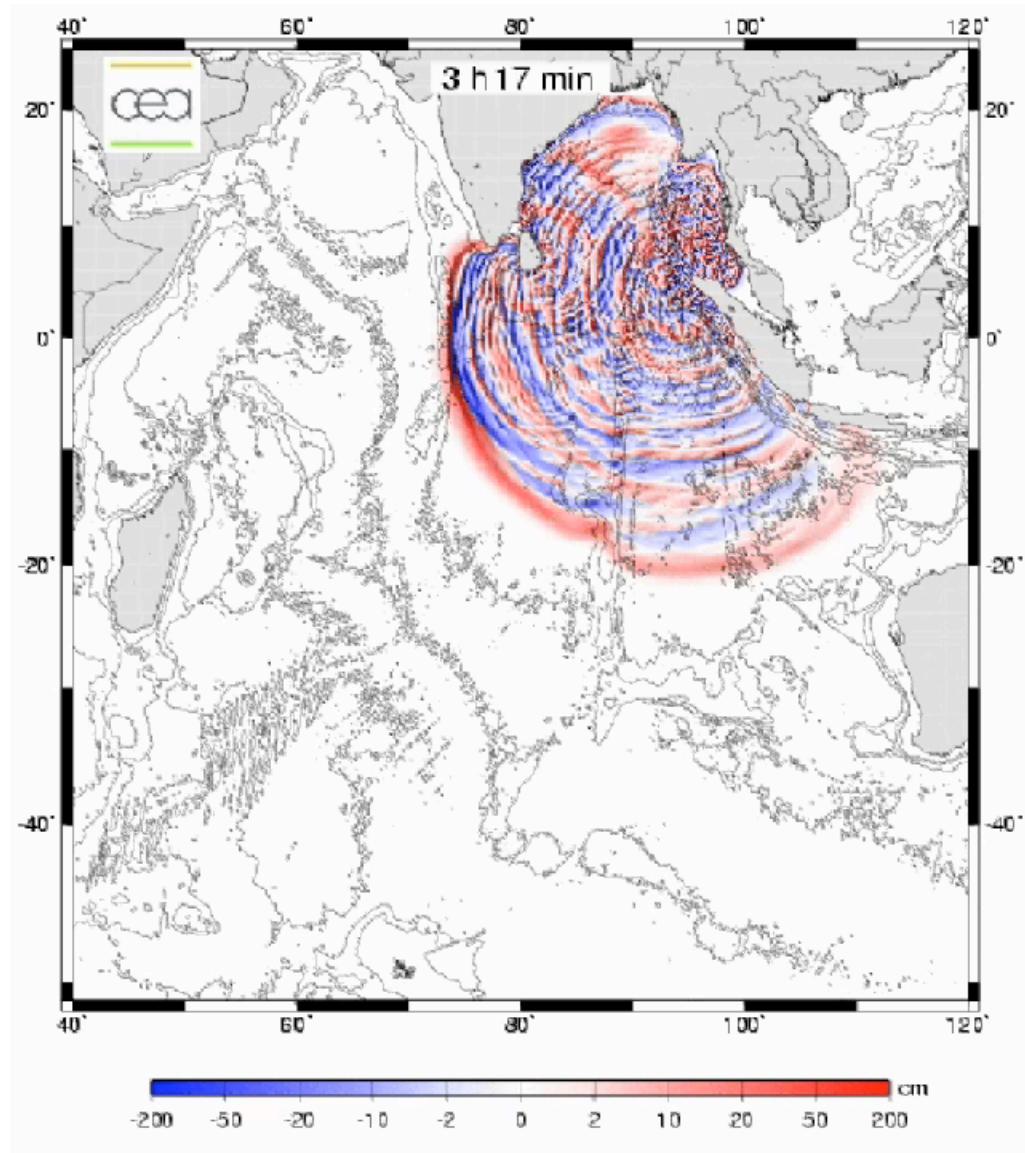
**ionospheric signature  
of tsunami waves**

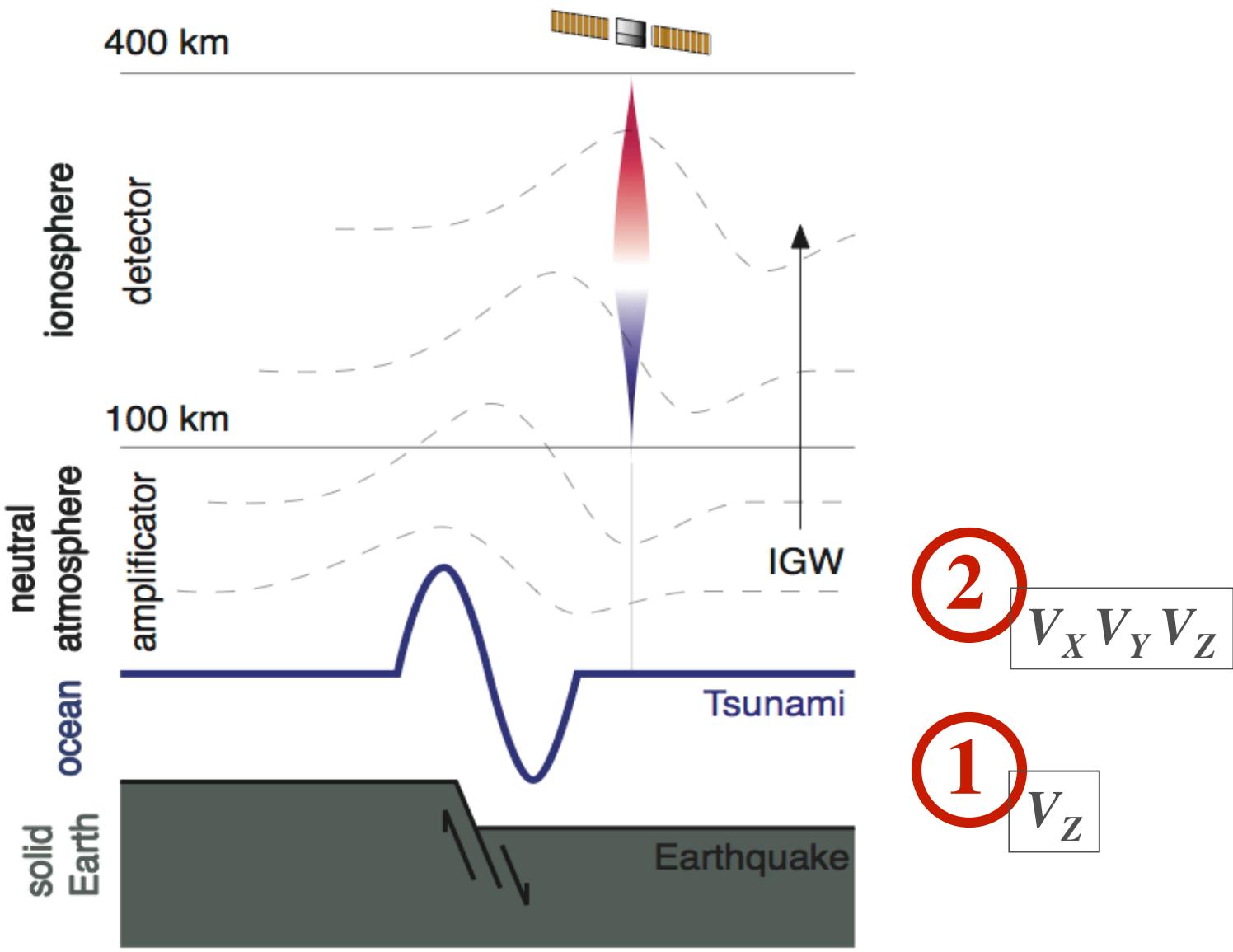
**tsunami wave**





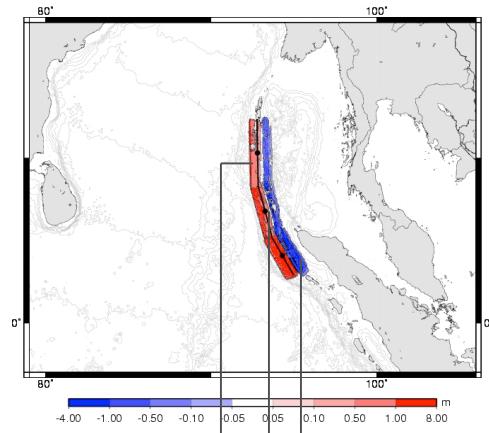
①  $V_Z$



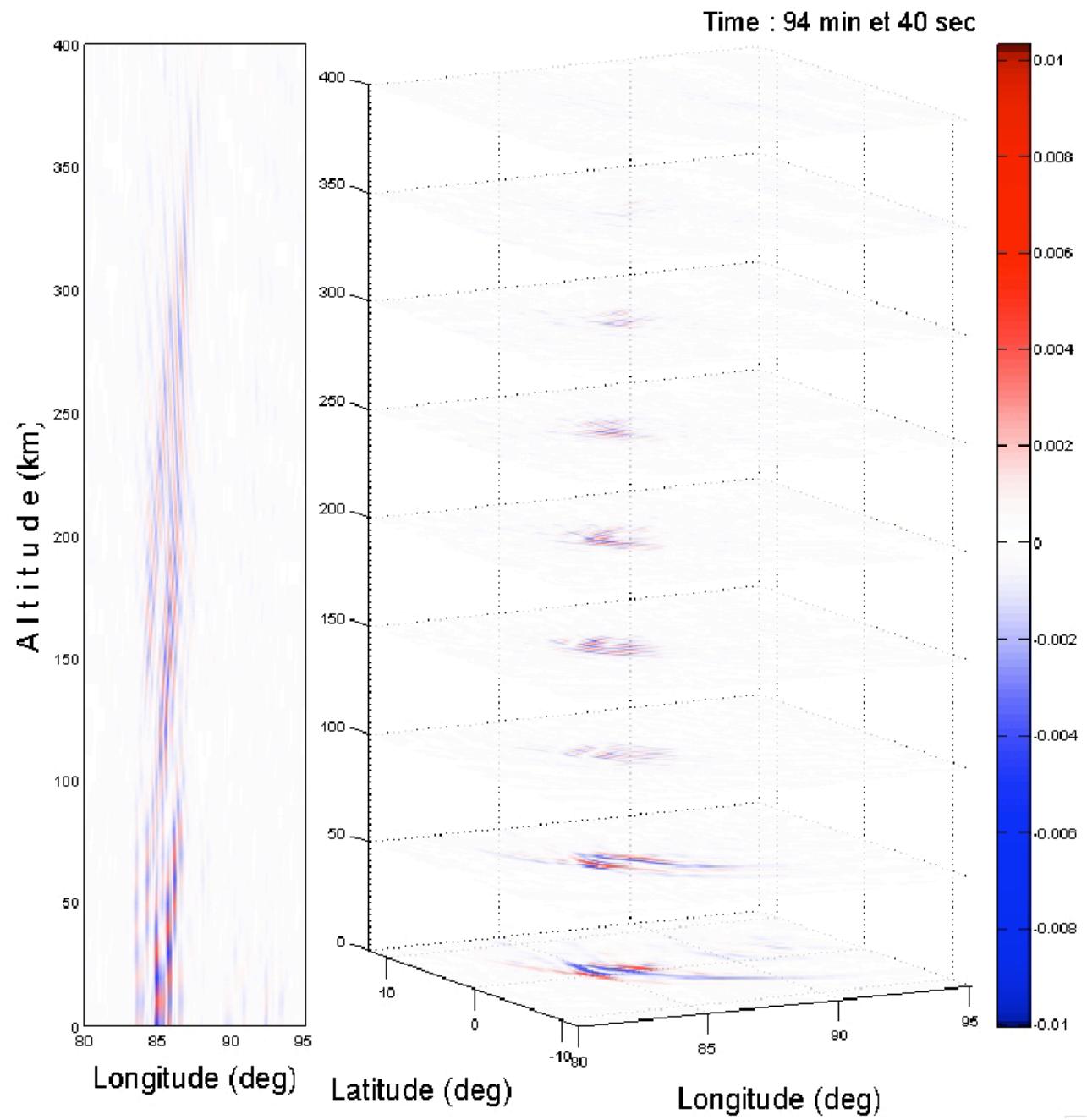


[Occhipinti et al., GRL, 2006]

*Sumatra tsunami*  
dec. 26th, 2004



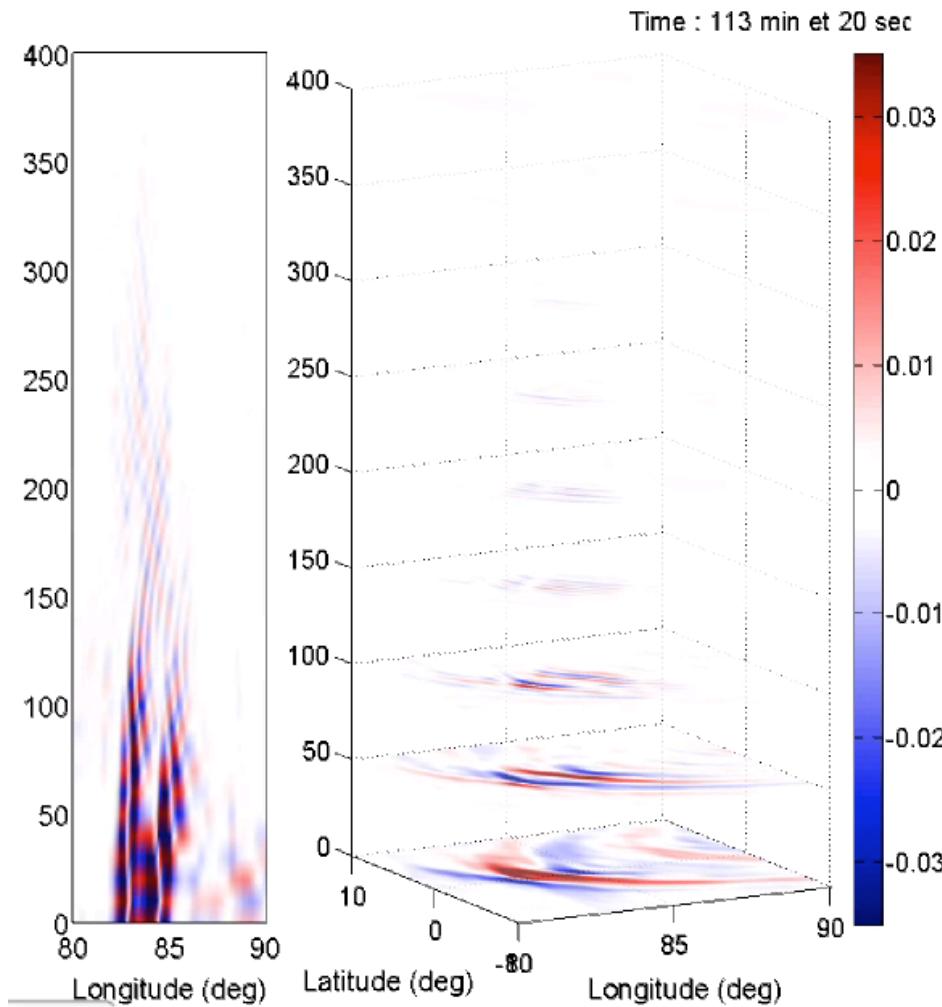
4 m  
6 m  
20 m



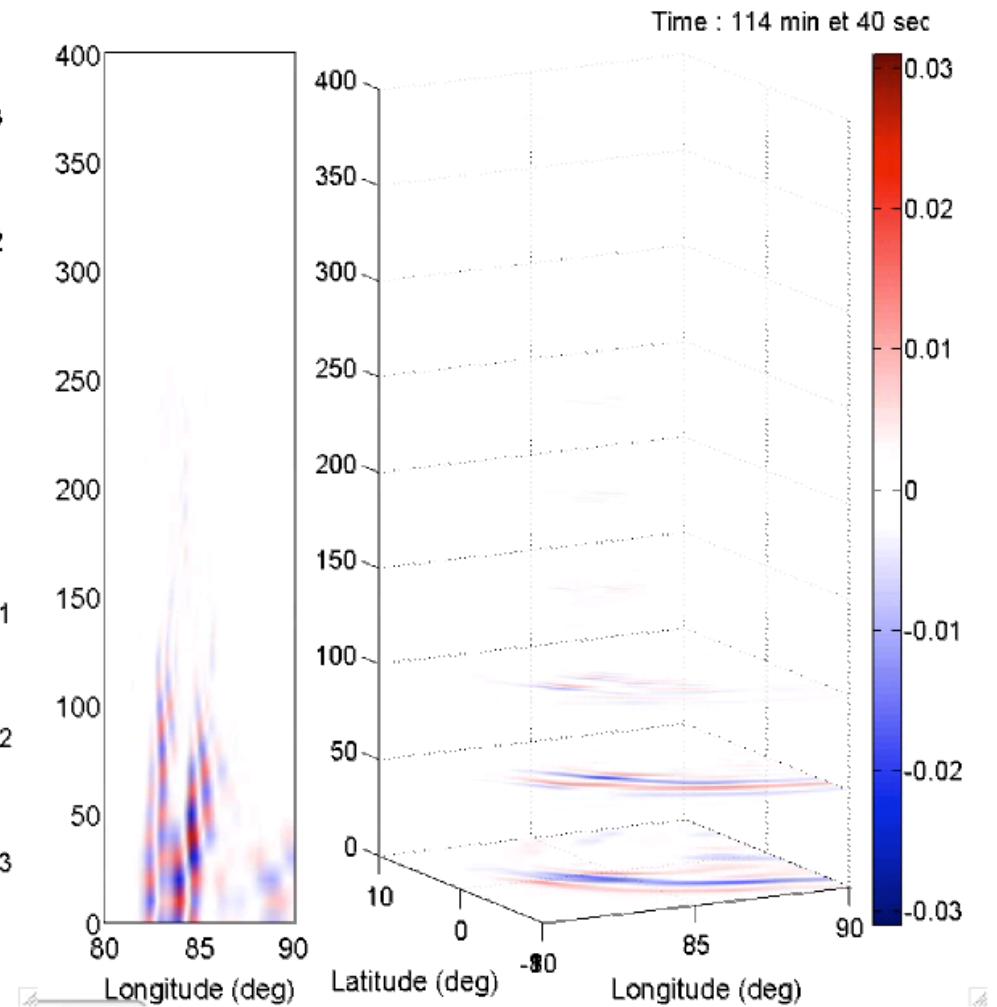
[Occhipinti et al., GRL, 2006]

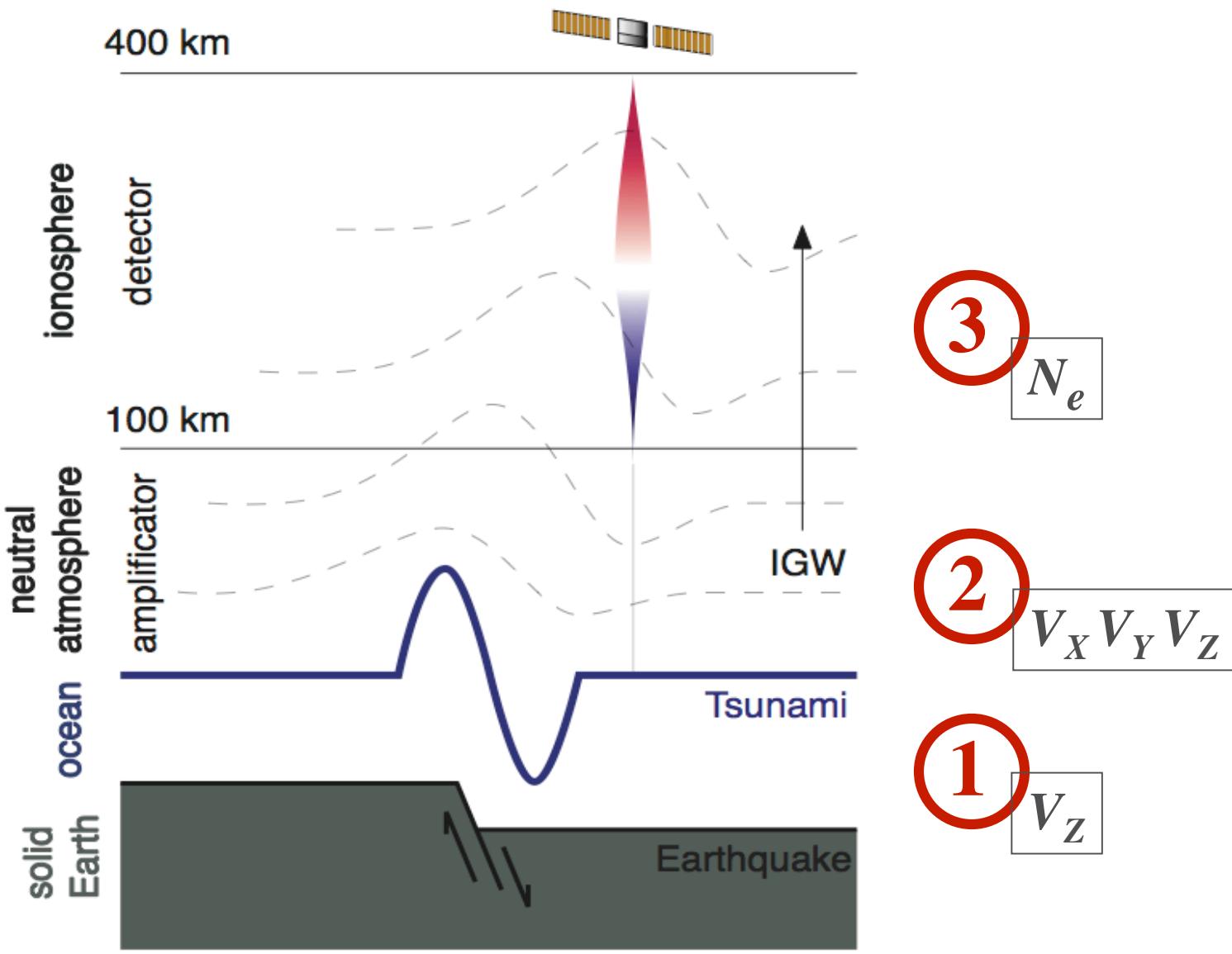
*complete movies in the GRL Supplementary Material on ninto's webpage: [www.ipgp.fr/~ninto](http://www.ipgp.fr/~ninto)*

## Est-West

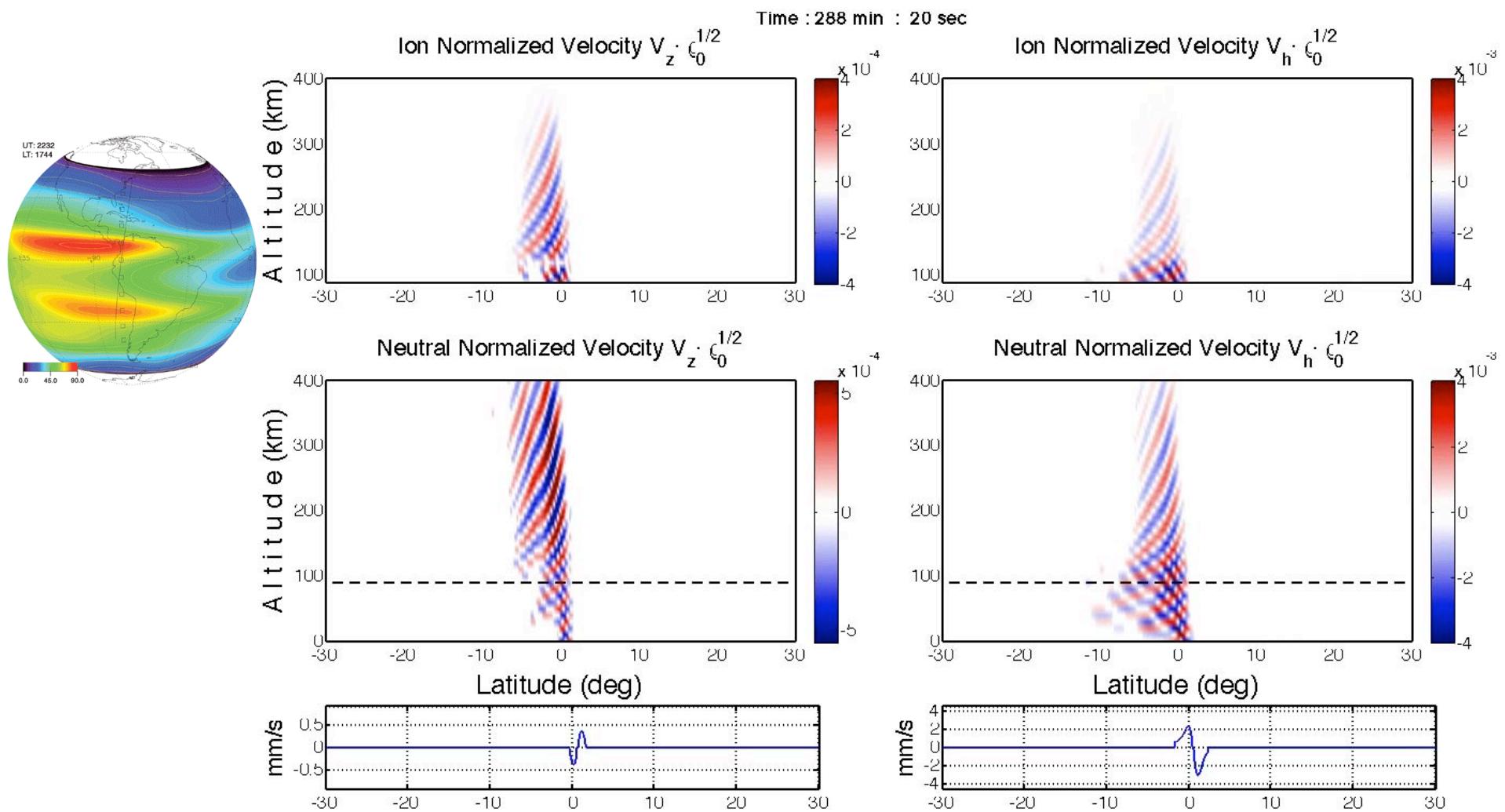


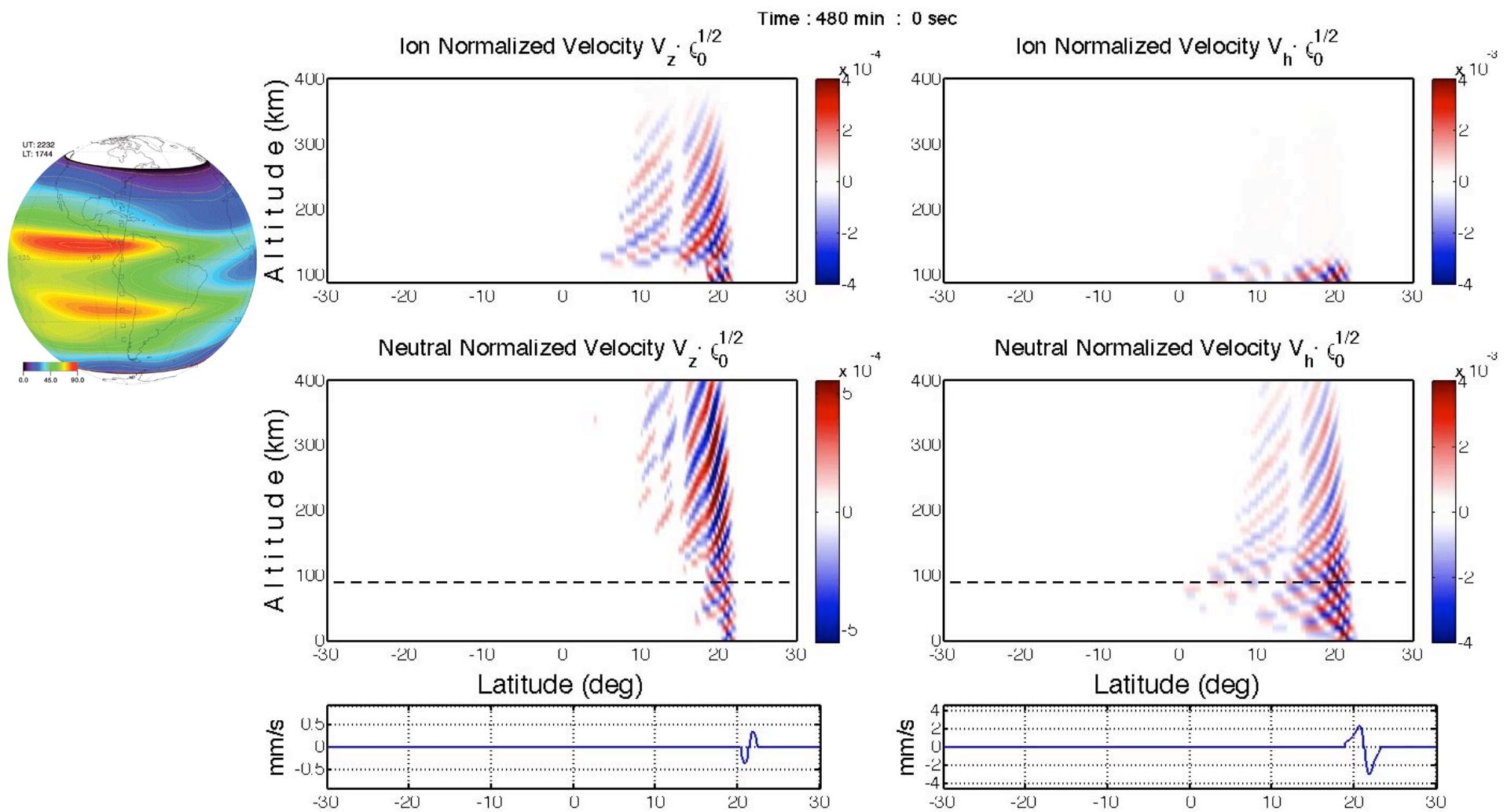
## Nord-Sud

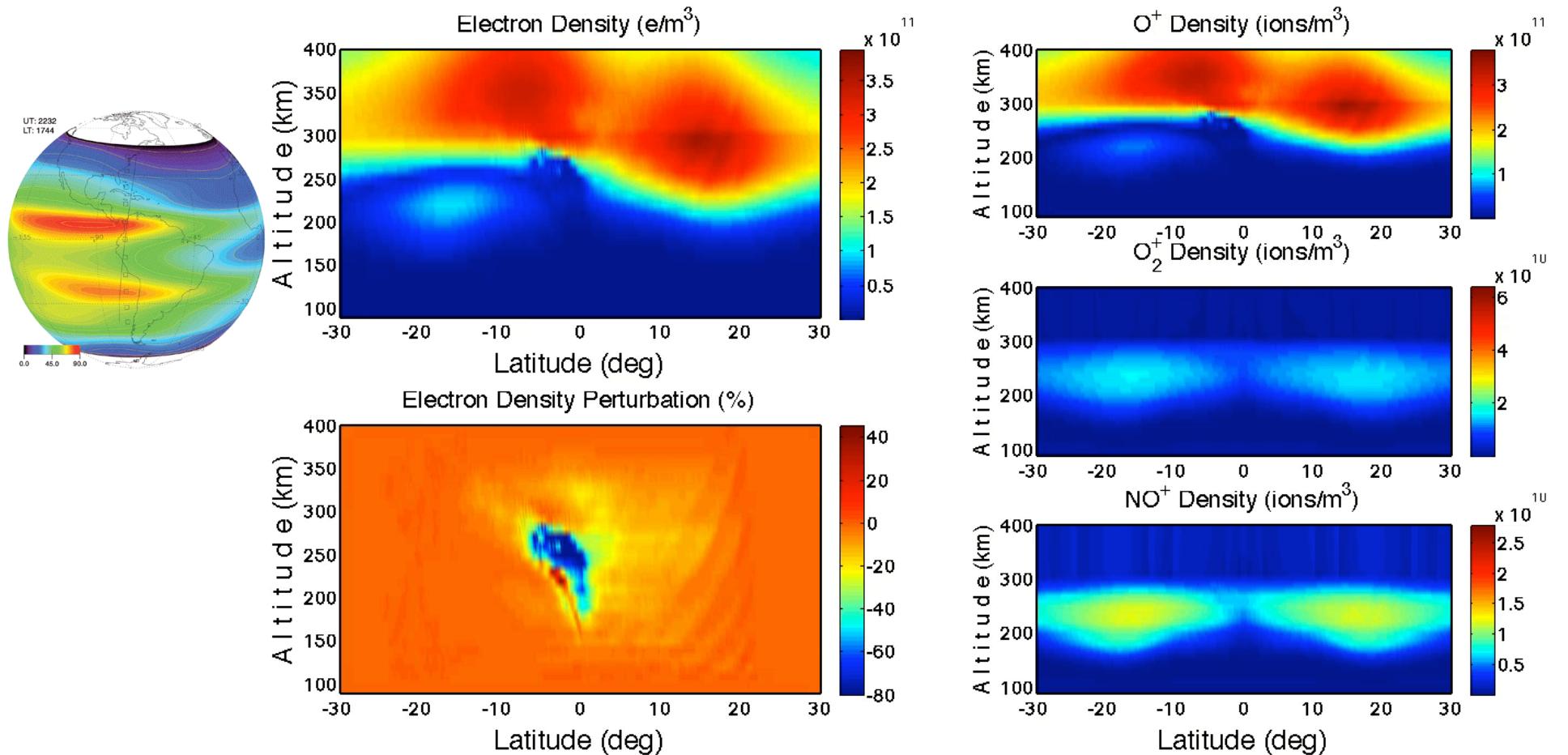




[Occhipinti et al., GRL, 2006]



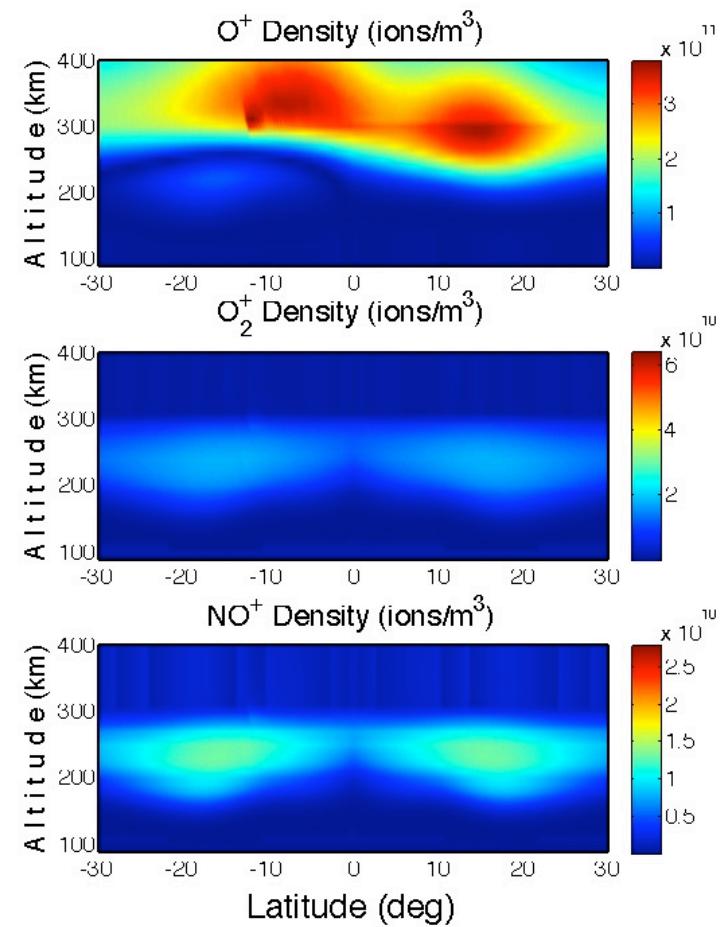
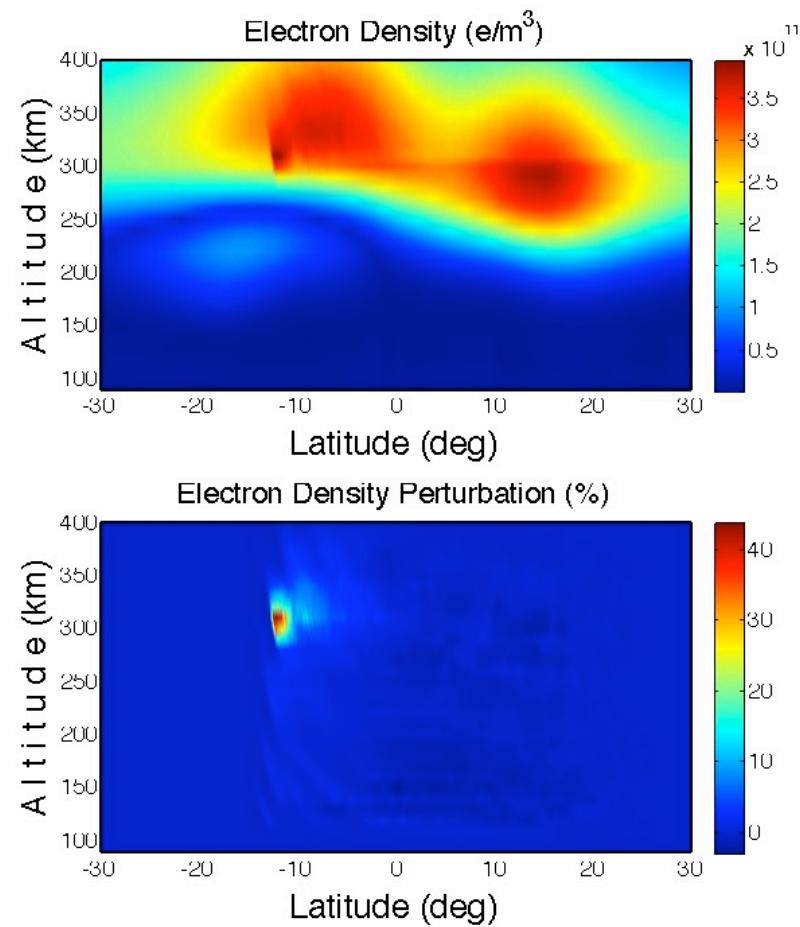
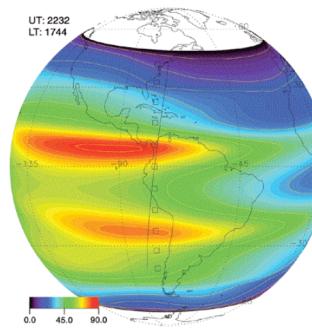




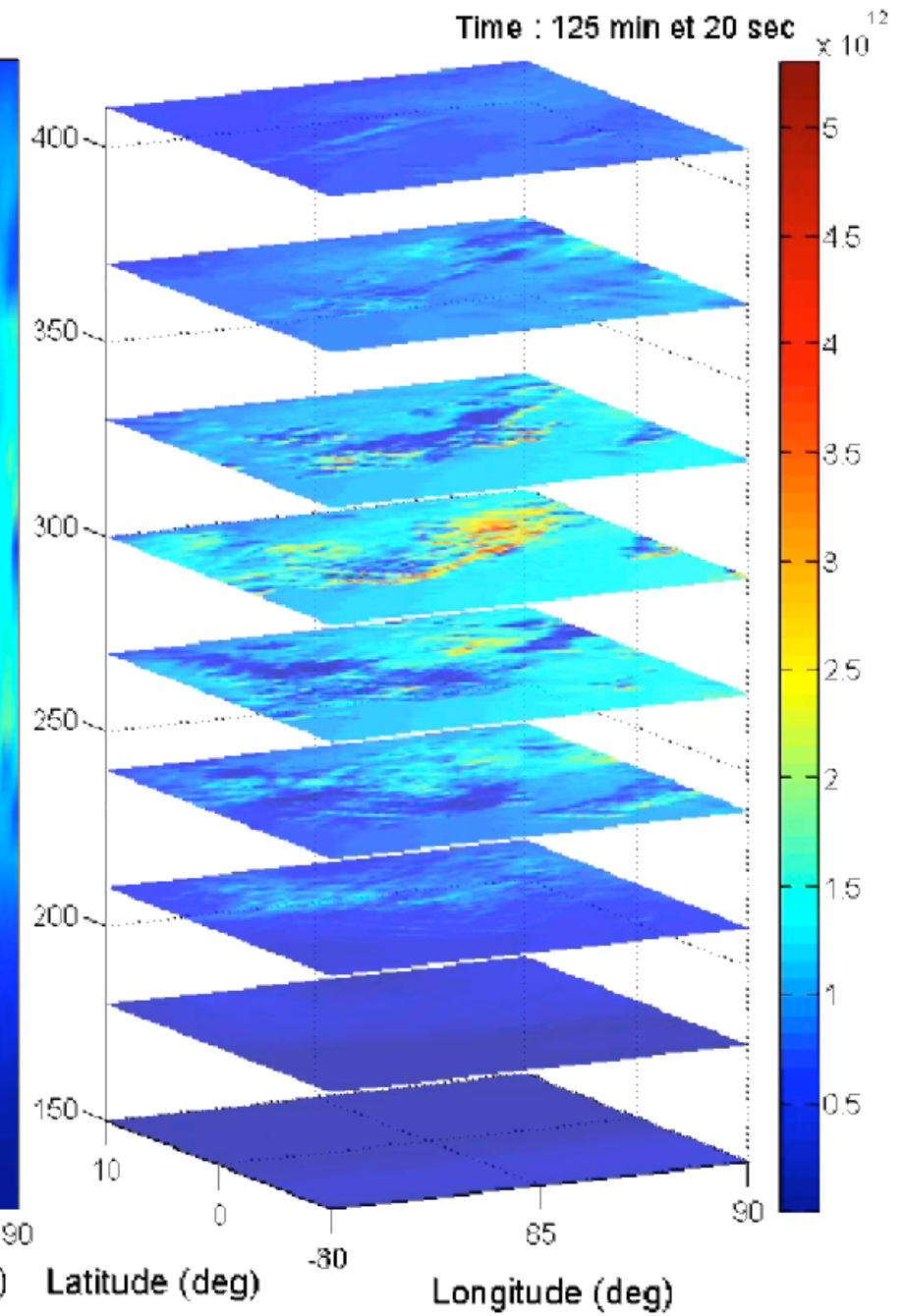
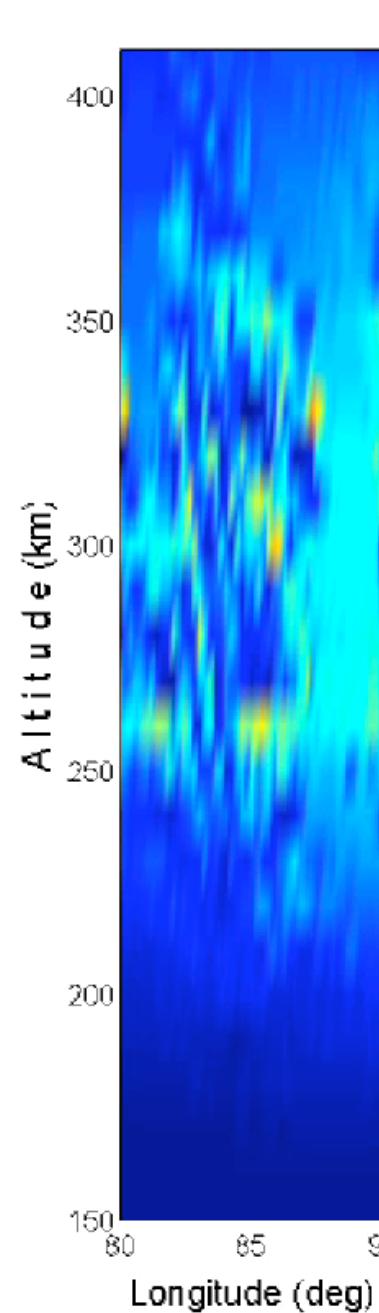
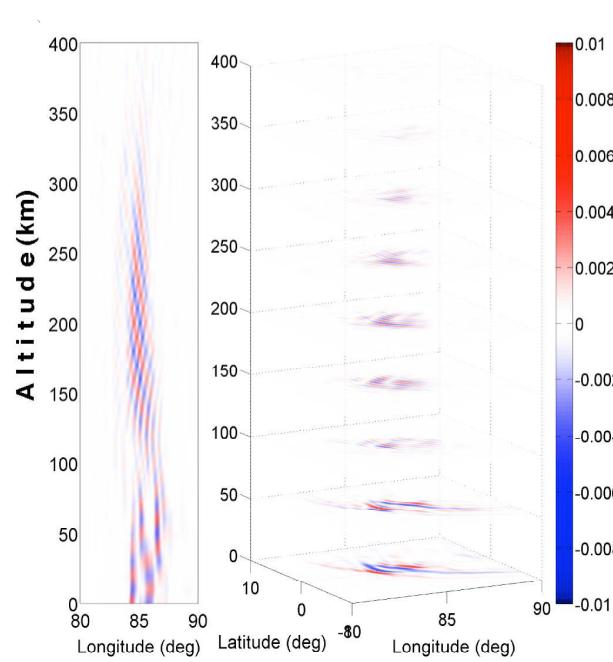
[Occhipinti *et al.*, GJI, 2008]

Northward propagation  
→

*complete movies in the GJI Supplementary Material on ninto's webpage: [www.ipgp.fr/~ninto](http://www.ipgp.fr/~ninto)*



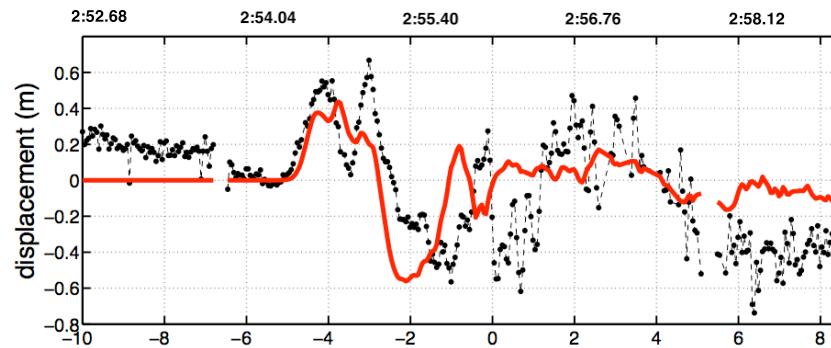
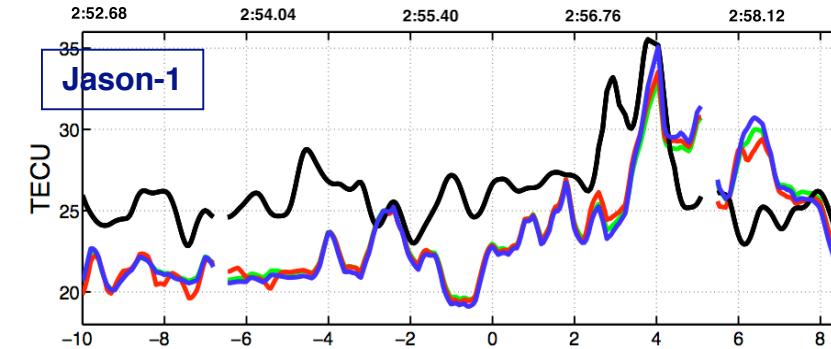
Southward propagation  
←



4

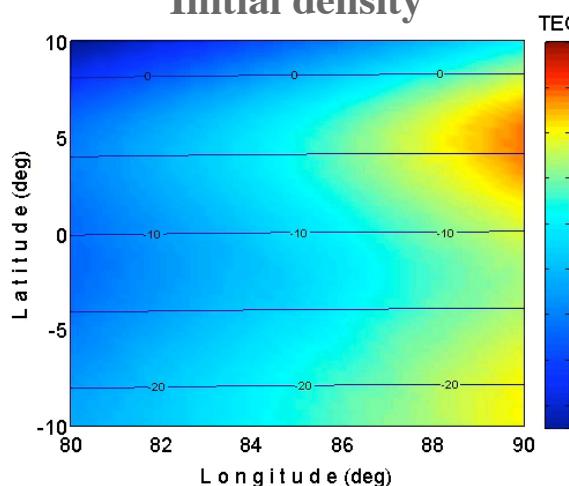
$$TEC = \int_{surf}^{sat} N_e ds$$

## Universal Time

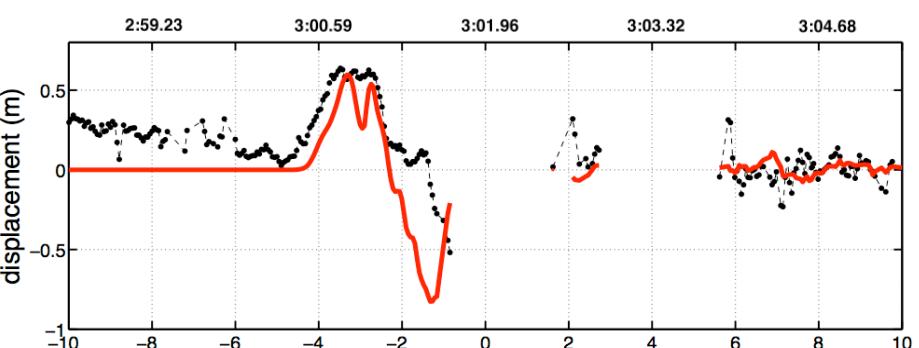
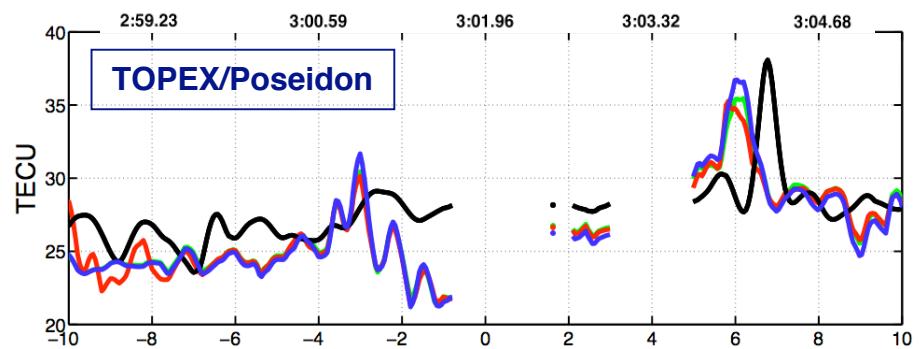


**Latitude (deg)**

Initial density

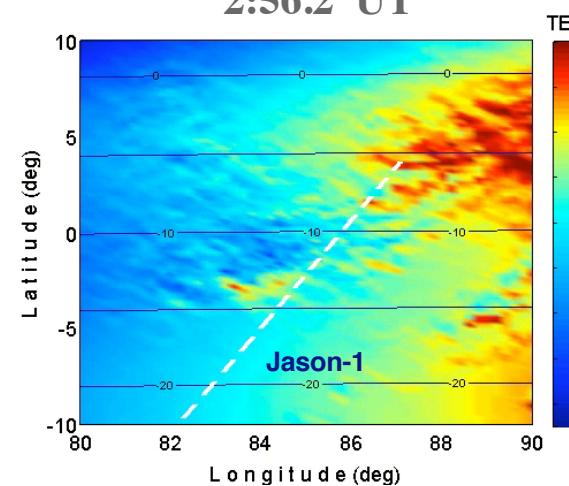


## Universal Time

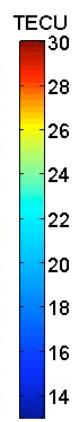
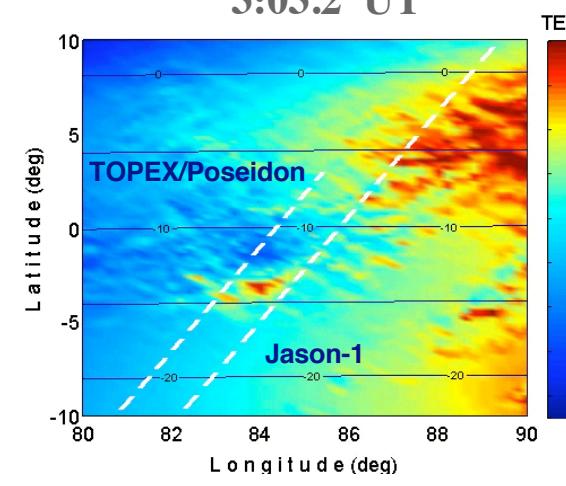


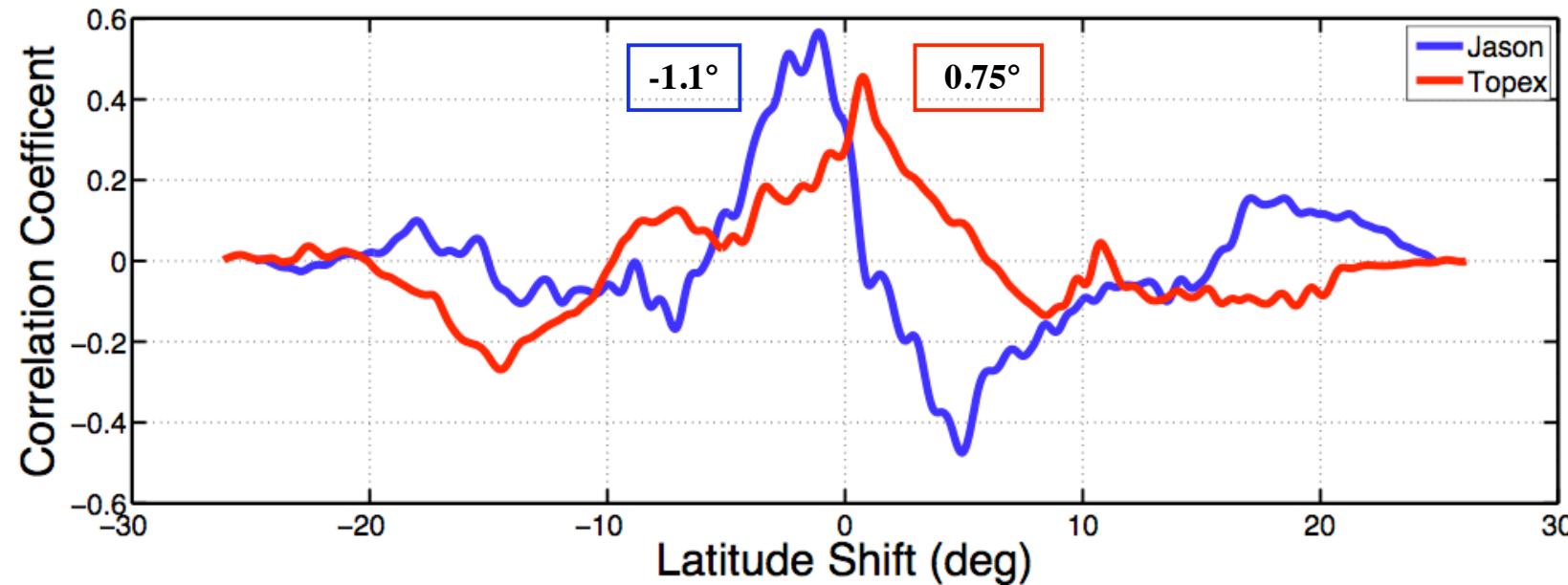
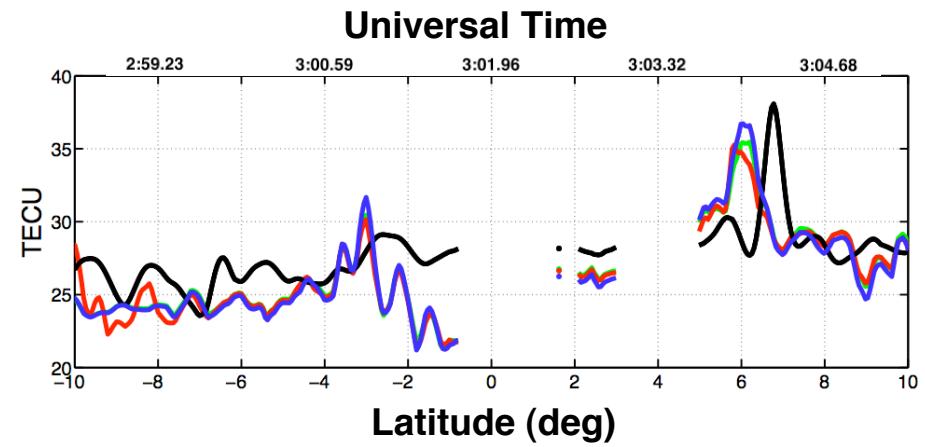
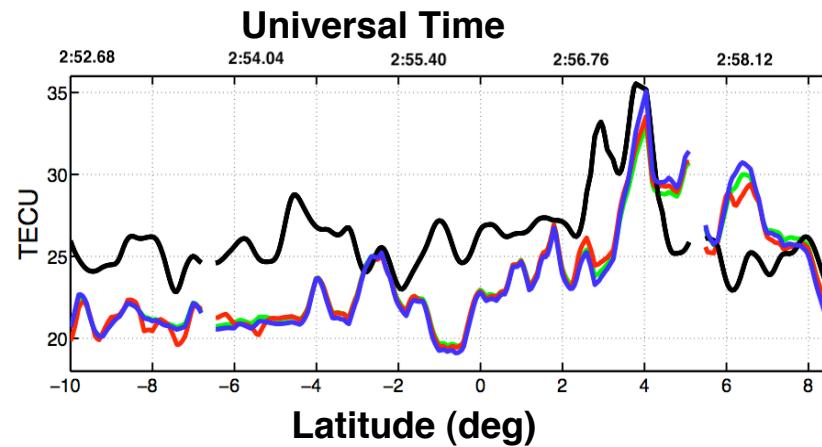
**Latitude (deg)**

3:03.2 UT

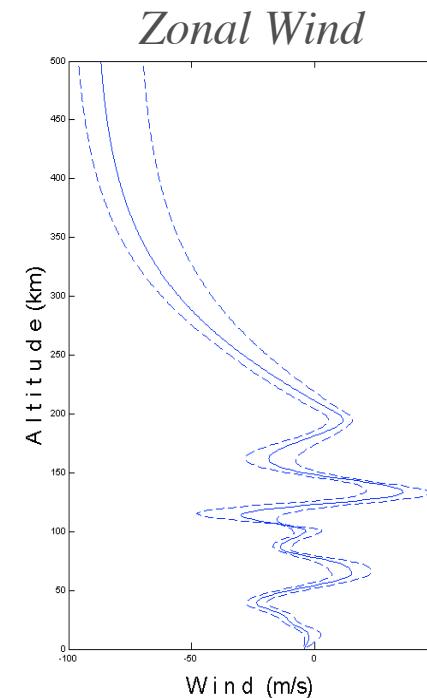
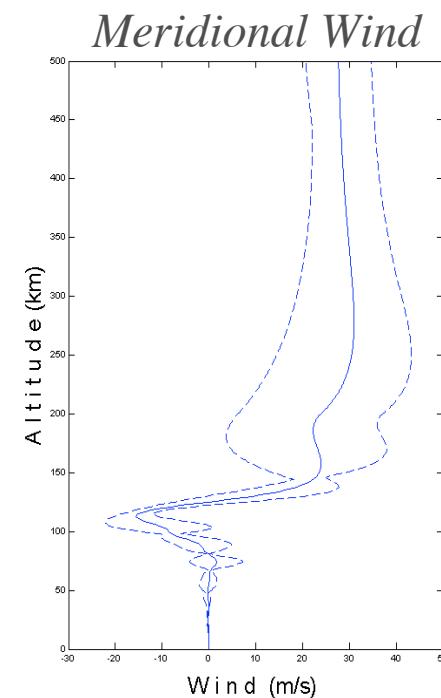
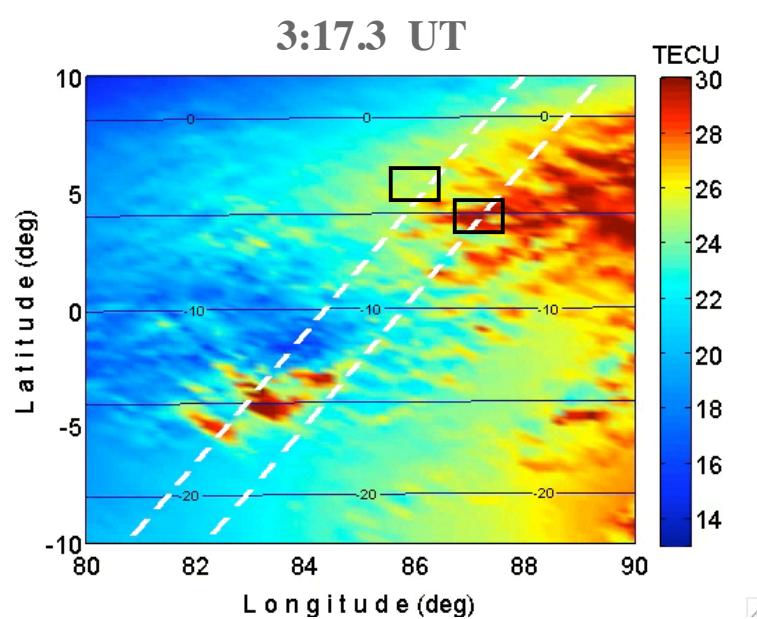
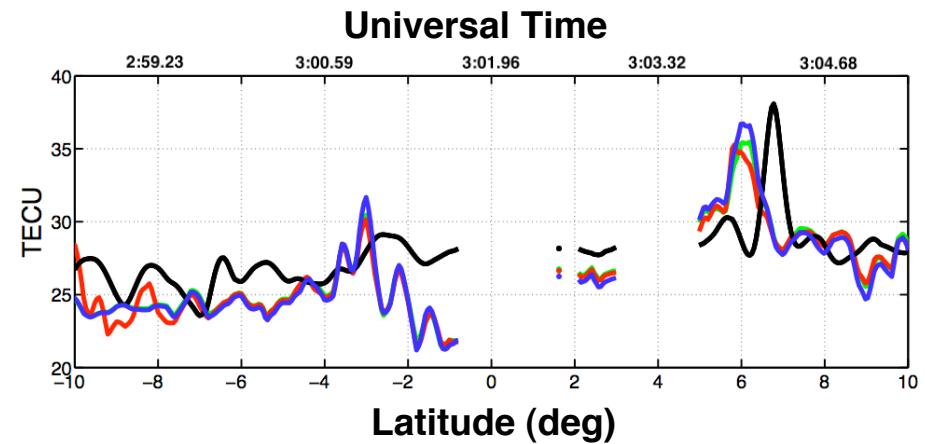
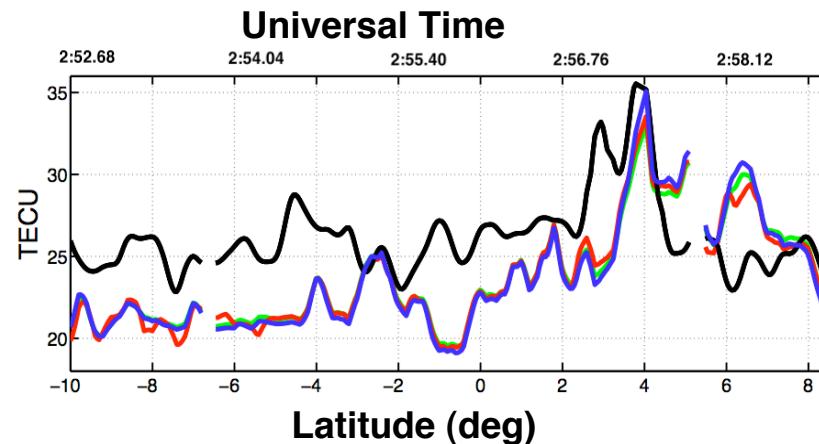


2:56.2 UT





*...for longitude  $\sim 0.2^\circ$  for both satellites*



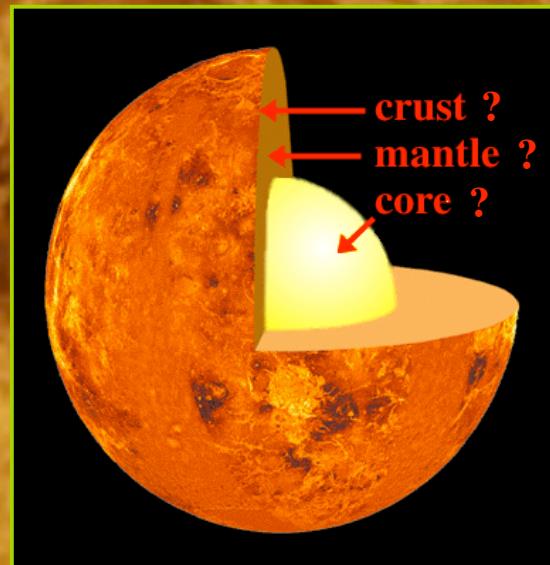
*shift*  
*latitude  $\sim 1^\circ$*   
*longitude  $\sim 1.5^\circ$*

Northward →  
**HWM93 model**

Eastward →

**Venera landers story**

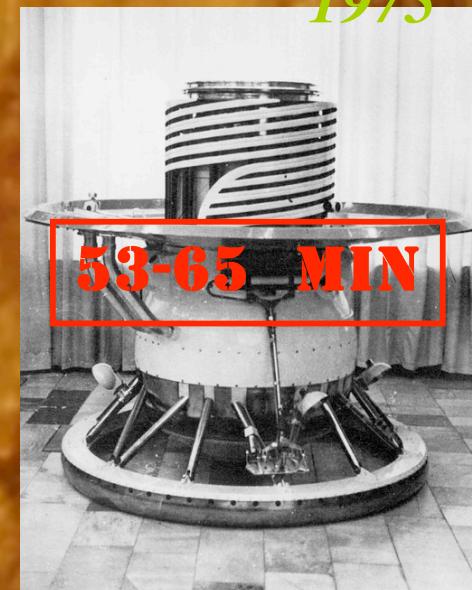
**1970**



**1965**



**1975**



**1981**

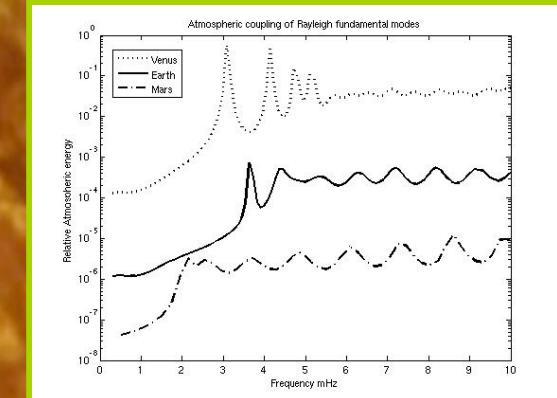
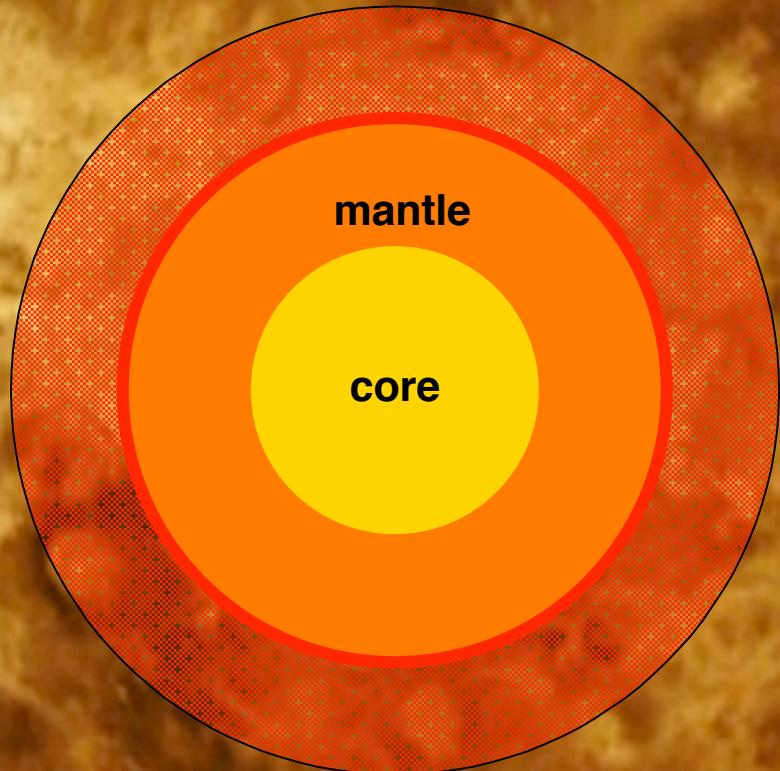


*Coupled system: Solid Planet + Atmosphere*

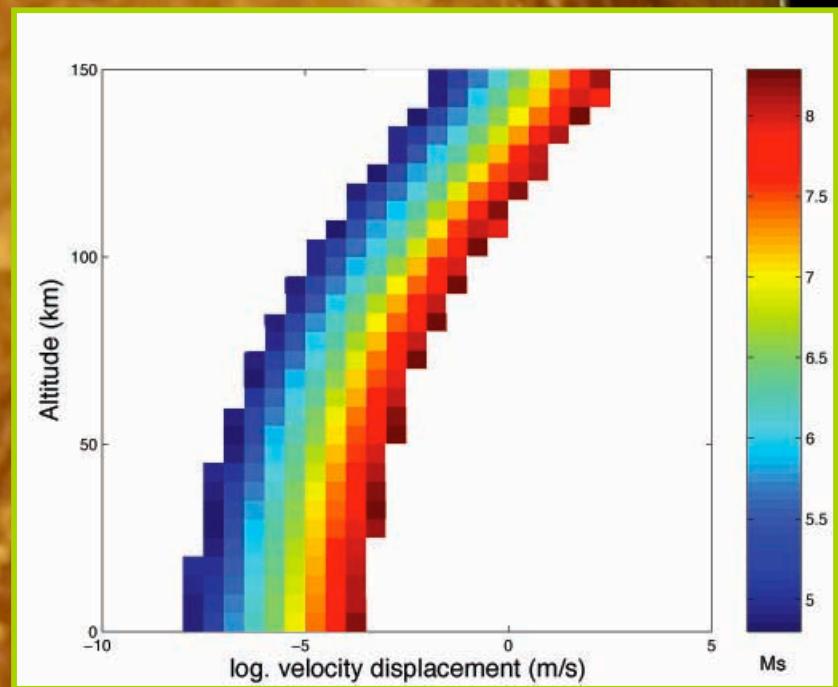
**Perfect gas hypothesis**



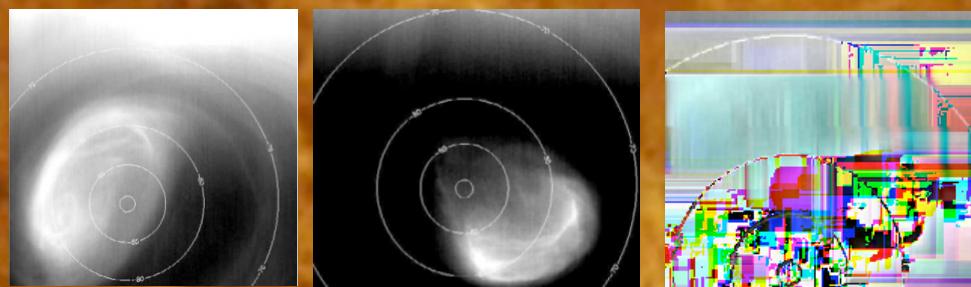
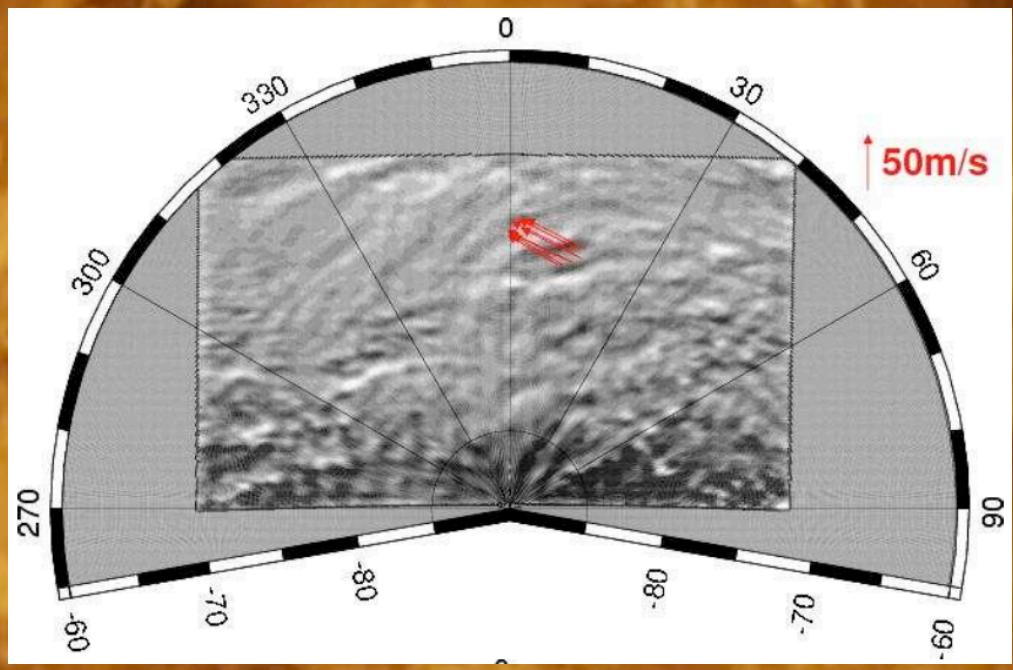
**Elastic behaviour of the atmosphere**



[Lognonné & Jhonson 2007]

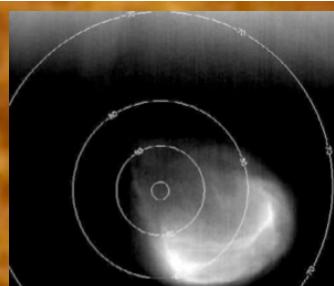
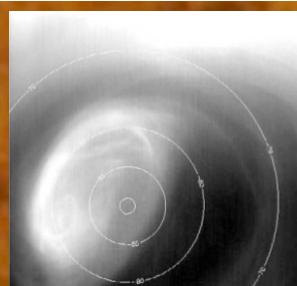
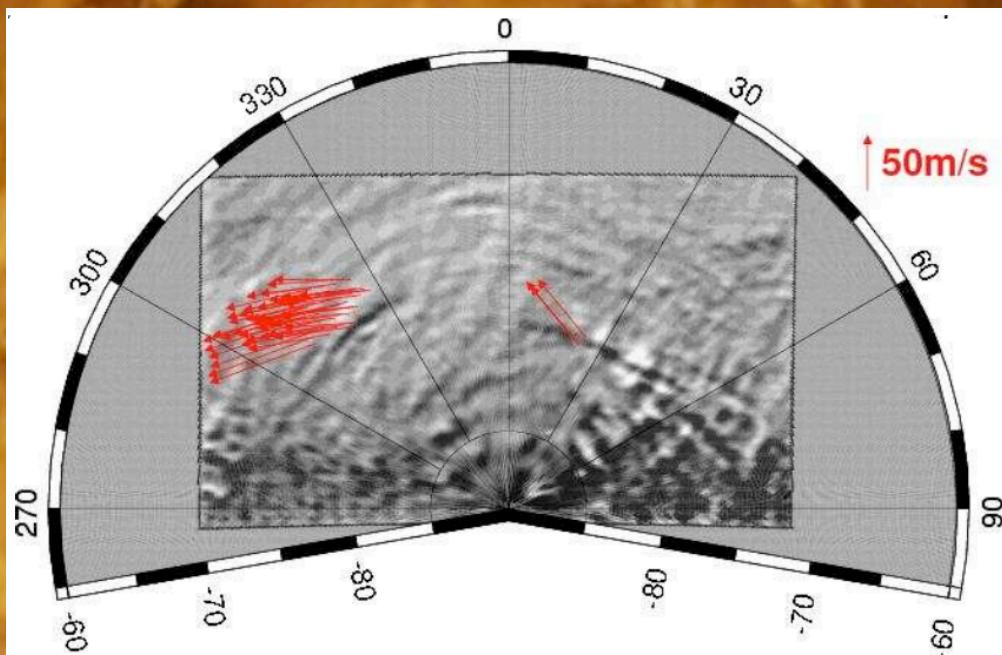


## Gravity Wave generated by Polar Vortex



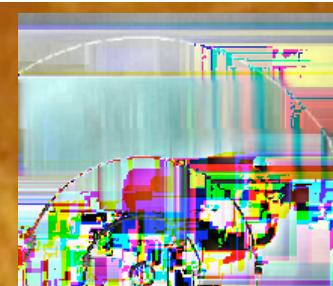
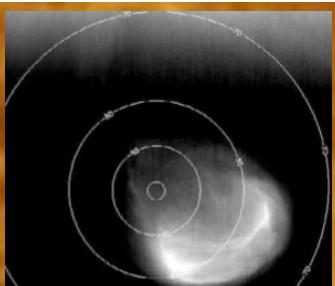
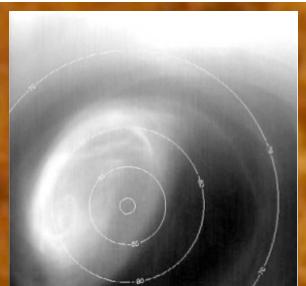
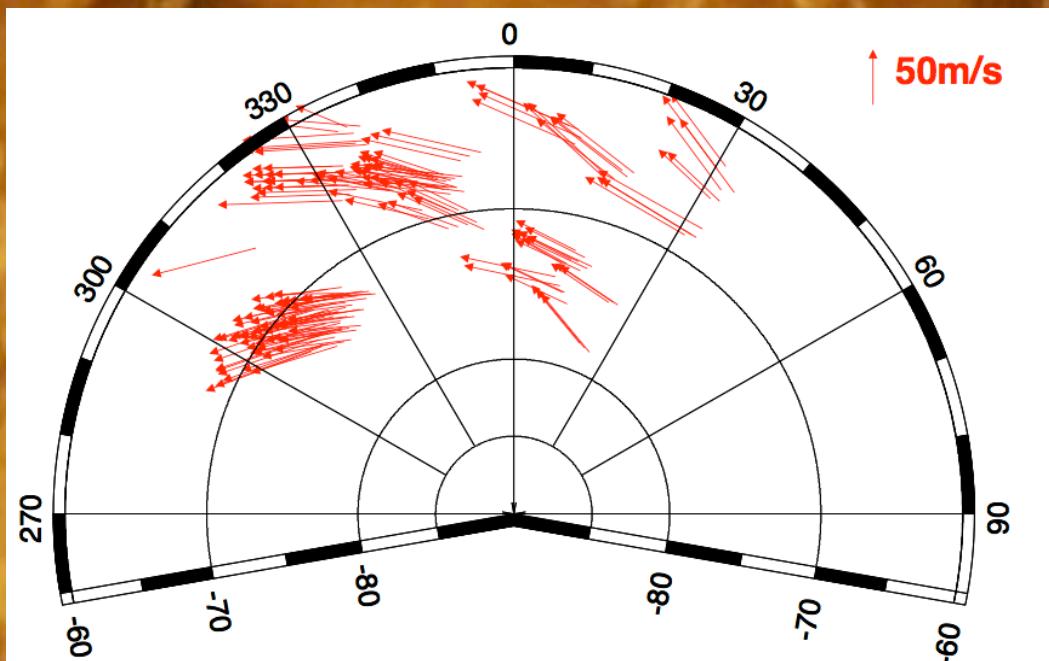
[Garcia et al., JGR 2009]

## Gravity Wave generated by Polar Vortex



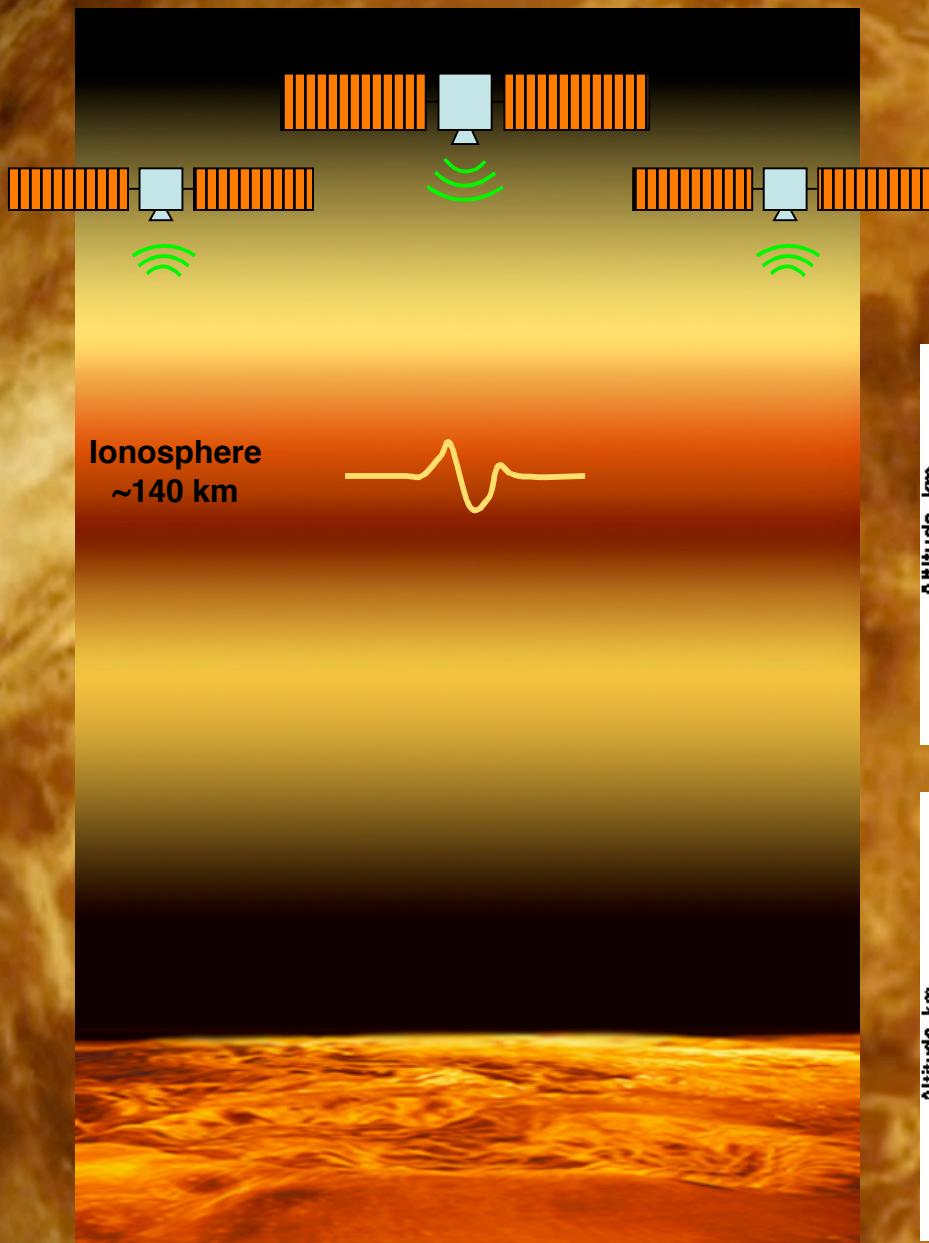
[Garcia et al., JGR 2009]

## Gravity Wave generated by Polar Vortex



[Garcia et al., JGR 2009]

## Mission concept



## Multi-frequency radar

*0.5-7 MHz  
and over 7 MHz*

