

# Daytime MALT neutral winds and their relationship with lower E region layers over Arecibo

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The formation of the lower layers (below 105km) has been a topic of controversy.

Krall et al., 2020 proposed that in the absence of the zonal wind, the meridional wind could form the lower layer.

Haldoupis and Shalimov 2021 argue that this is not possible because the contribution factor for the zonal wind is higher than for the meridional wind.

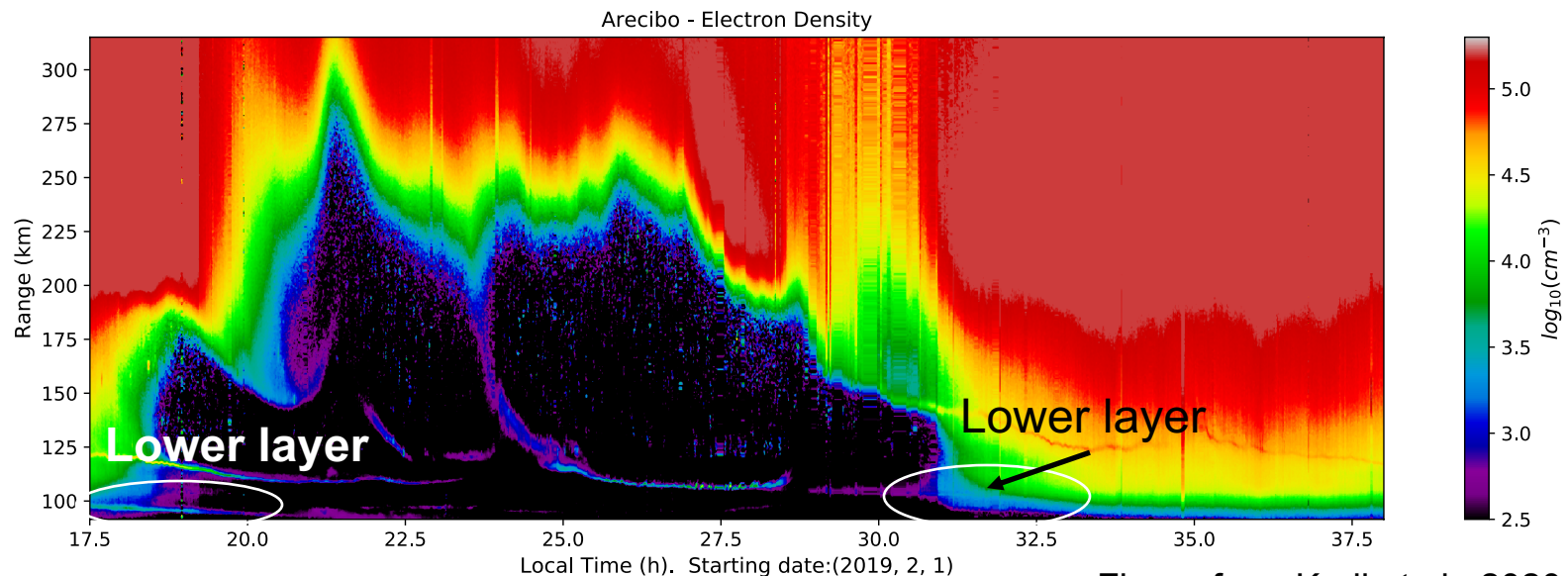


Figure from Krall et al., 2020

# Unique set of data with descending layers and neutral winds

Arecibo – dual beam data  
Neutral winds 95km -130 km

- Hysell et al., 2014 proposed a technique to estimate neutral winds using the dual beam capabilities at Arecibo.
- During two World Day campaigns in 2013 and 2014 this mode was performed, where layers, neutral winds, temperatures and other neutral fluid parameters can be observed in the MALT region from altitudes between 95 km to 130 km.

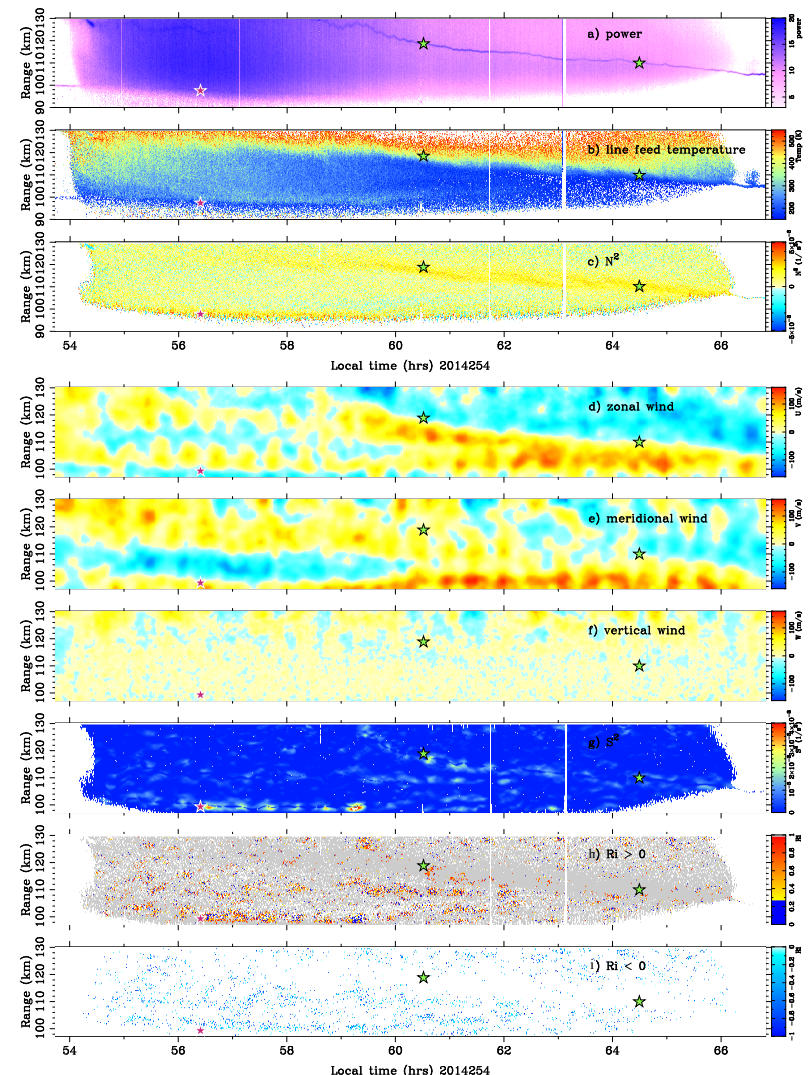
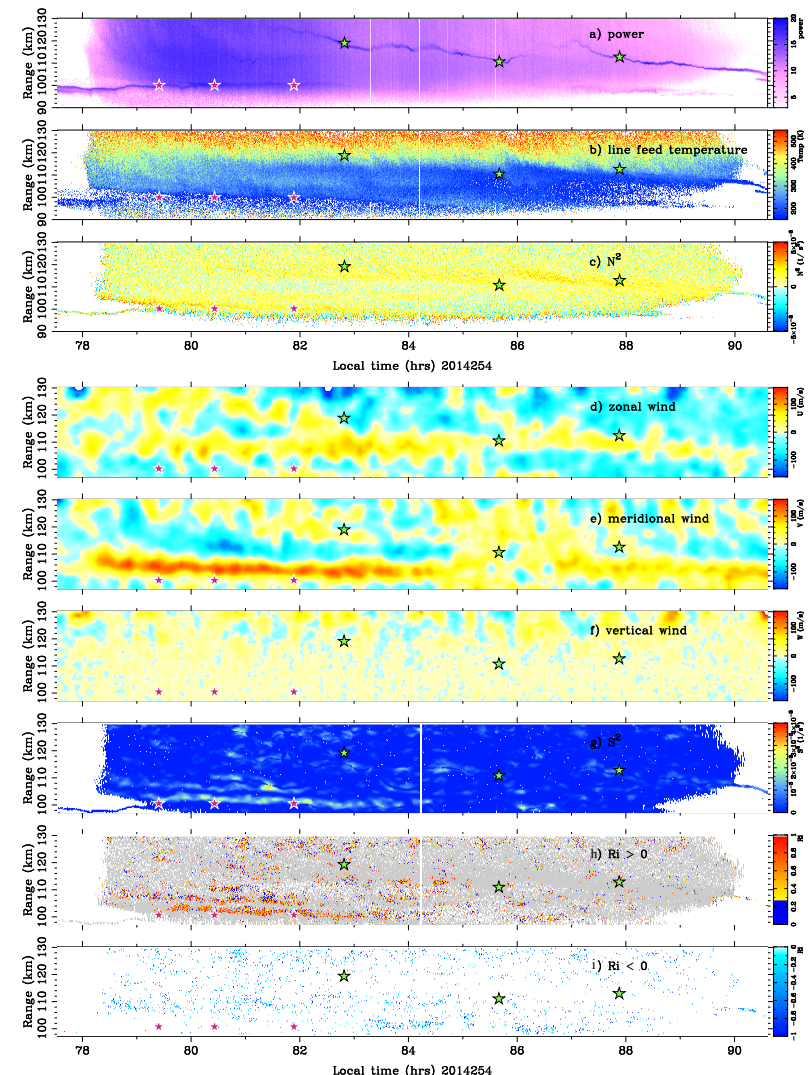


Figure from Nossa, 2016

# Unique set of data with descending layers and neutral winds

Arecibo – dual beam data  
Neutral winds 95km -130 km

- Neutral winds are the main explanation for the descending metallic layer formation.
- However, the short term variability of the layers can be explained using neutral fluid parameters, like Shear or the Richardson number. This set of data allow us to obtain these parameters.
- For some days, dominant meridional winds are observed in conjunction with the low altitude layers (★).





# Layer formation mechanism (assuming magnetic field dipole)

For the northern hemisphere

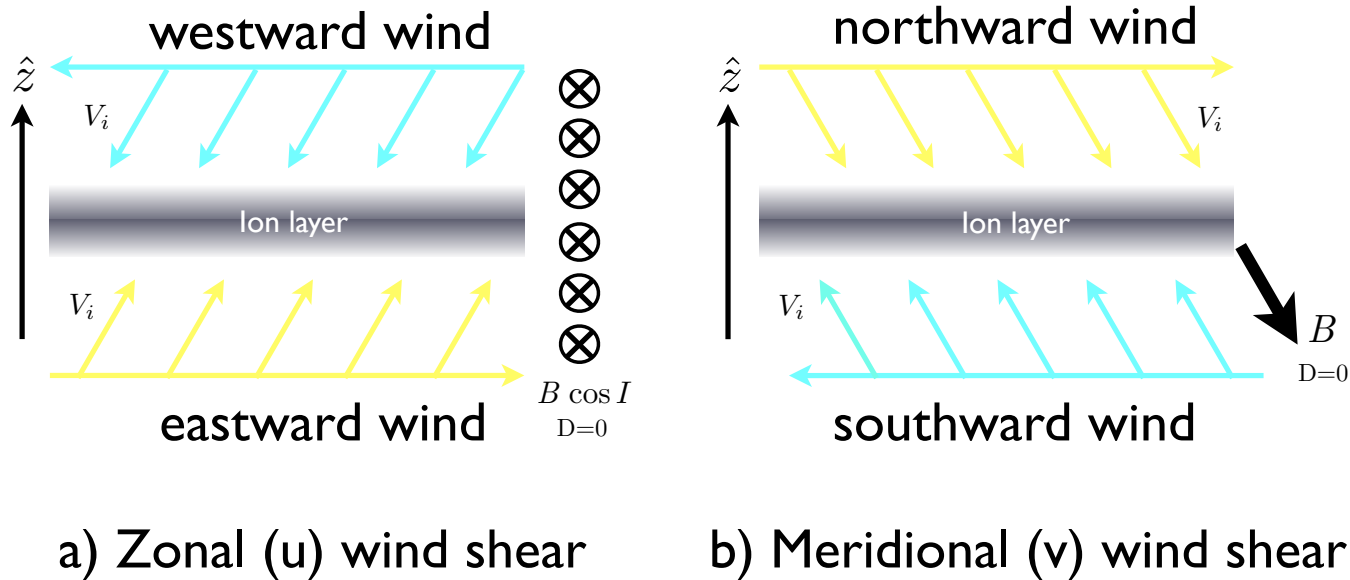
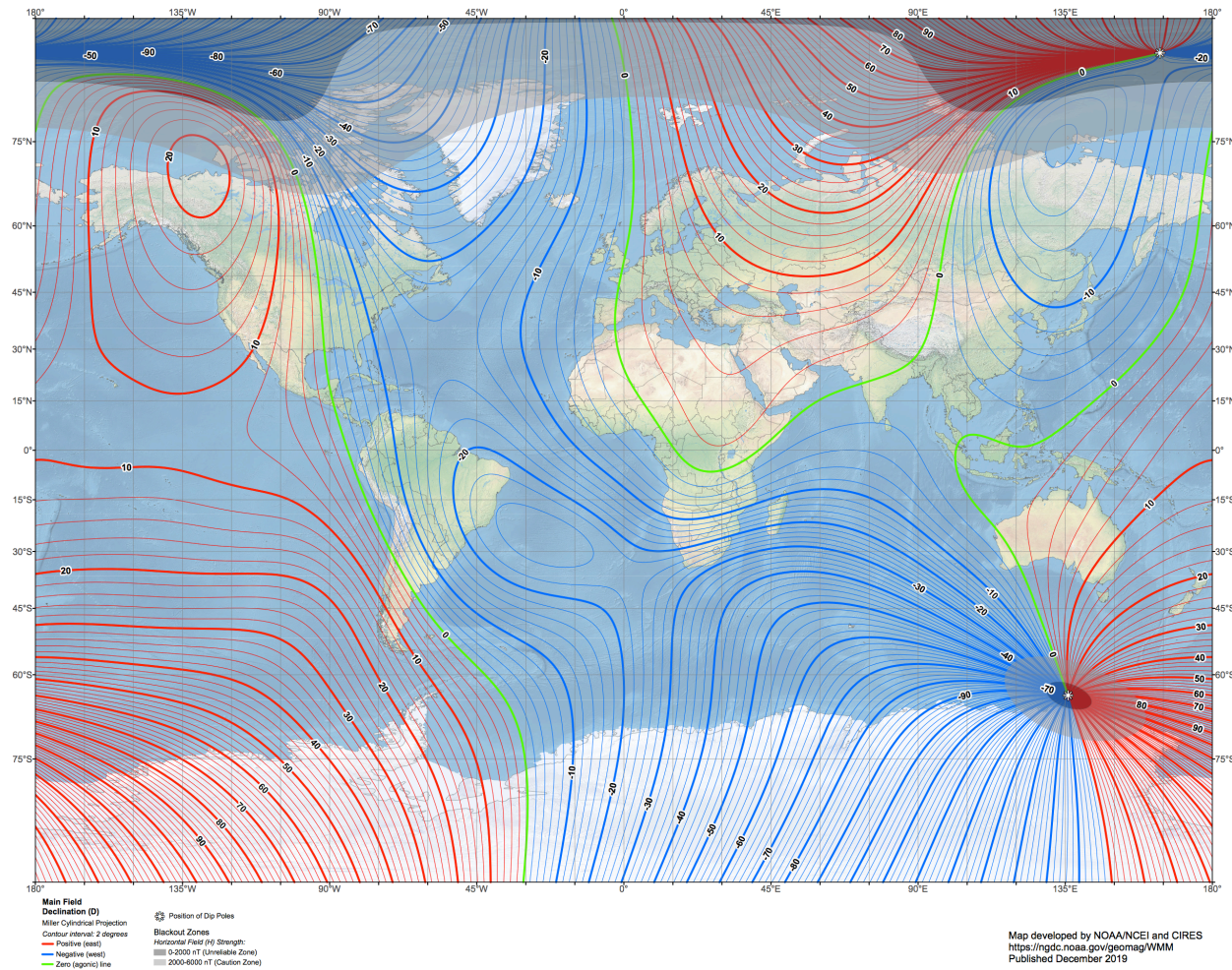


Figure adapted from Haldoupis, 2011

# Declination is negative for the Caribbean and the US East coast

US/UK World Magnetic Model - Epoch 2020.0  
Main Field Declination (D)



Map taken from NOAA's webpage

# Vertical ion drift (assuming magnetic field with $D \neq 0$ )

A complete expression for the vertical ion drift is obtained, including Declination ( $D$ ):

$$\begin{aligned}
 v_z = & -\frac{\cos I}{B_o} E_\phi \\
 & + r_o \frac{\alpha \cos I}{B_o} E_p \\
 & + (\sin^2 I + r_o \alpha^2 \cos^2 I) w \\
 & + r_o (\cos I \sin I \sin D - \alpha \cos I \cos D) u \\
 & + r_o (\sin I \cos I \cos D + \alpha \cos I \sin D) v
 \end{aligned}$$

with:

$$\begin{aligned}
 r_o &= (1 + \alpha^2)^{-1}, r_1 = \alpha r_o, r_2 = \alpha^2 r_o, \\
 \text{where } \alpha &= \nu / \Omega \\
 \nu &\text{ is the ion-neutral collision frequency} \\
 \Omega &\text{ is the ion gyro frequency}
 \end{aligned}$$

Neglecting the electric field contribution:

$$V_z = f_w w + f_u u + f_v v$$

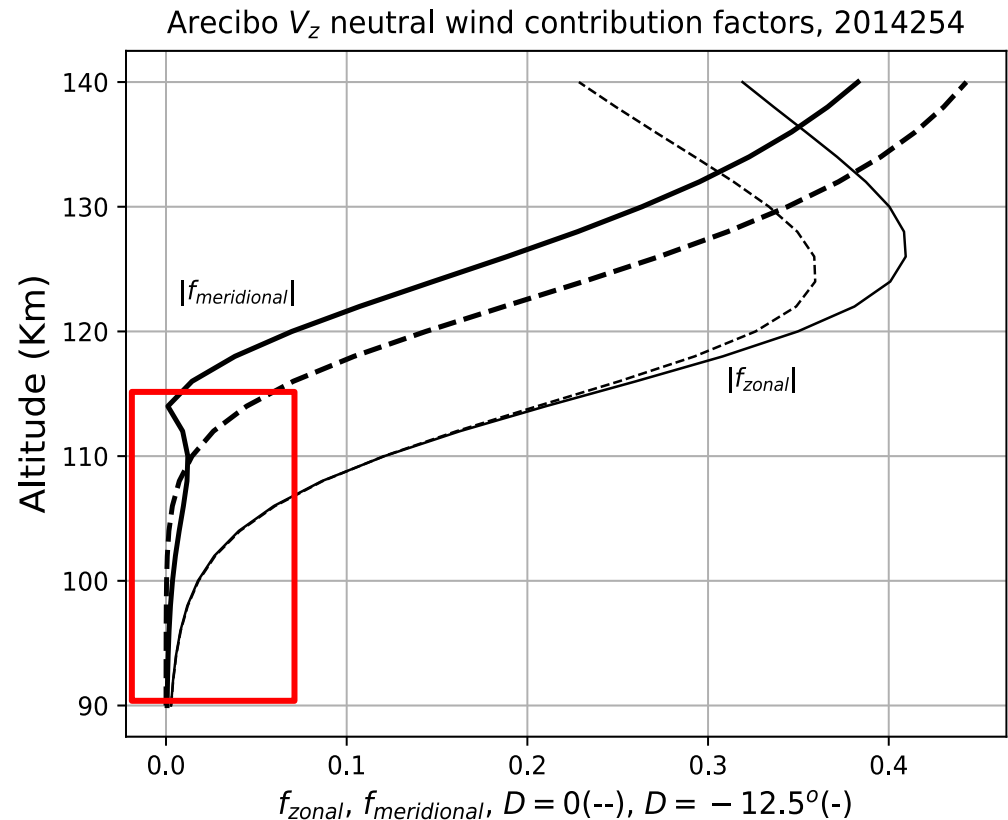
where  $f_u, f_v$  are the horizontal wind contribution factors.

Assumptions:

- Neglect ion inertia
- Quasi neutrality
- Ignoring effects of gravity pressure gradients and electron-neutral collisions

# Zonal and Meridional wind contributions

- Traditional methods ( $D=0$ ) showed that the contribution factors don't change the sign.
  - However, when considering  $D<0$  over Arecibo, the contribution factor ratio changes for lower altitudes ( $h \lesssim 115$  km).
- 1. Meridional winds become more important.
2. Meridional shear mechanism is reversed below 115 km.

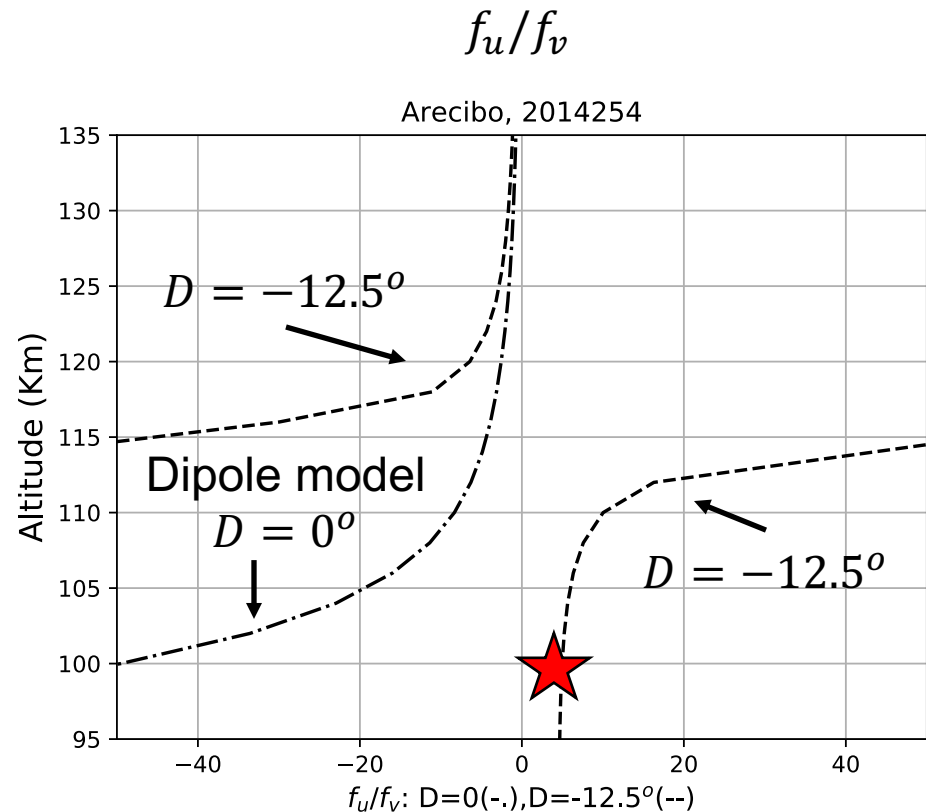




# 1. Ratio of the wind factor contribution

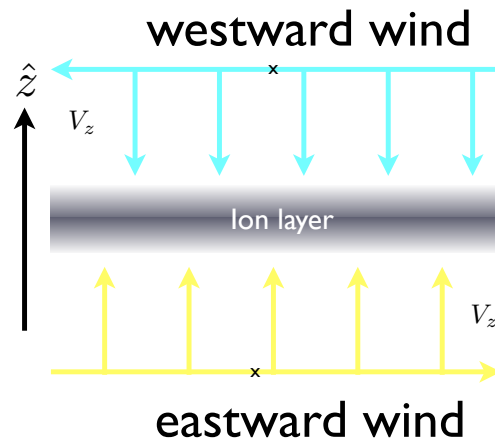
## 1. Meridional winds become more important

- The ratio of the contribution factors of the winds show that for the traditional method ( $D = 0^\circ$ ), the meridional winds had to be at least 50 times greater than the zonal winds to have an impact in the formation of the layers.
- However, when using  $D = -12.5^\circ$ , the ratio shows that the meridional winds have to be only 5 times greater than the zonal winds. Examples of those magnitudes are found in the data.

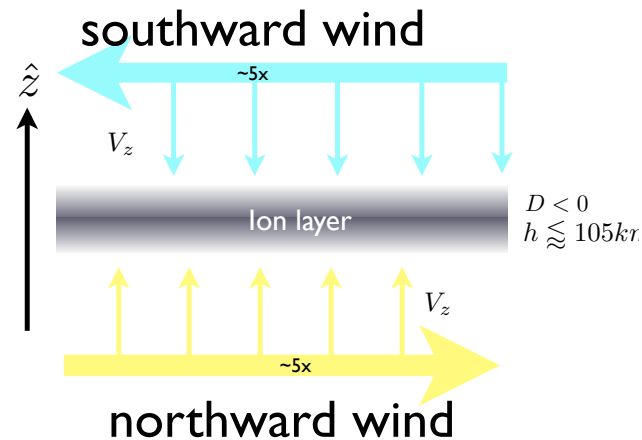


# New layer formation mechanism for lower altitudes when $D < 0$

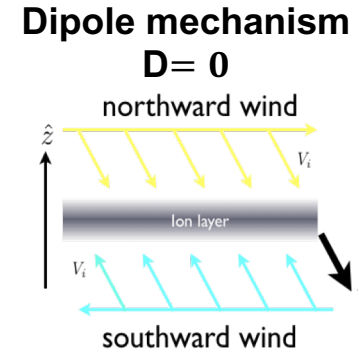
## 2. Meridional shear mechanism is reversed below 115 km.



a) Zonal (u) wind shear

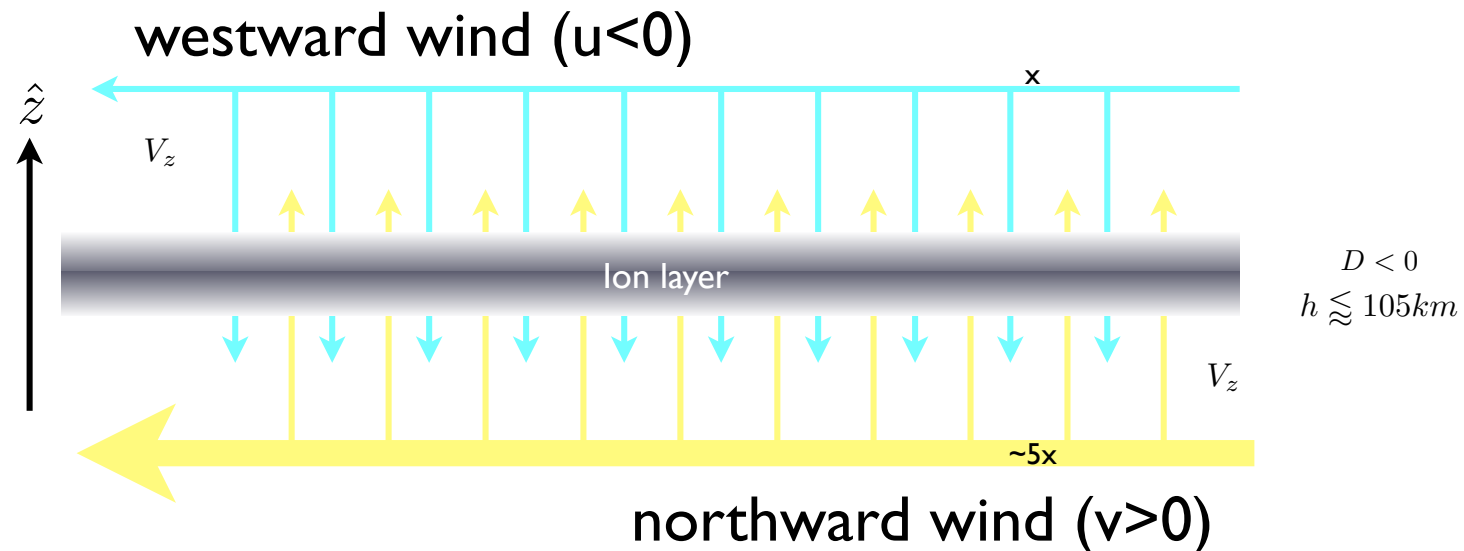


b) Meridional (v) wind shear



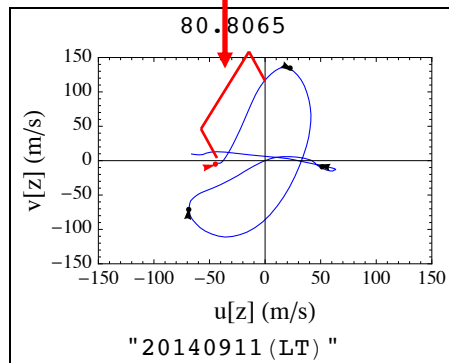
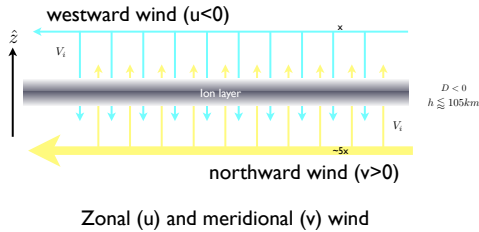
- Negative declination means that because  $f_v < 0$  below 115 km over Arecibo, then the meridional wind should be reversed to form a layer at that altitude.

# New layer formation mechanism for lower altitudes when $D < 0$



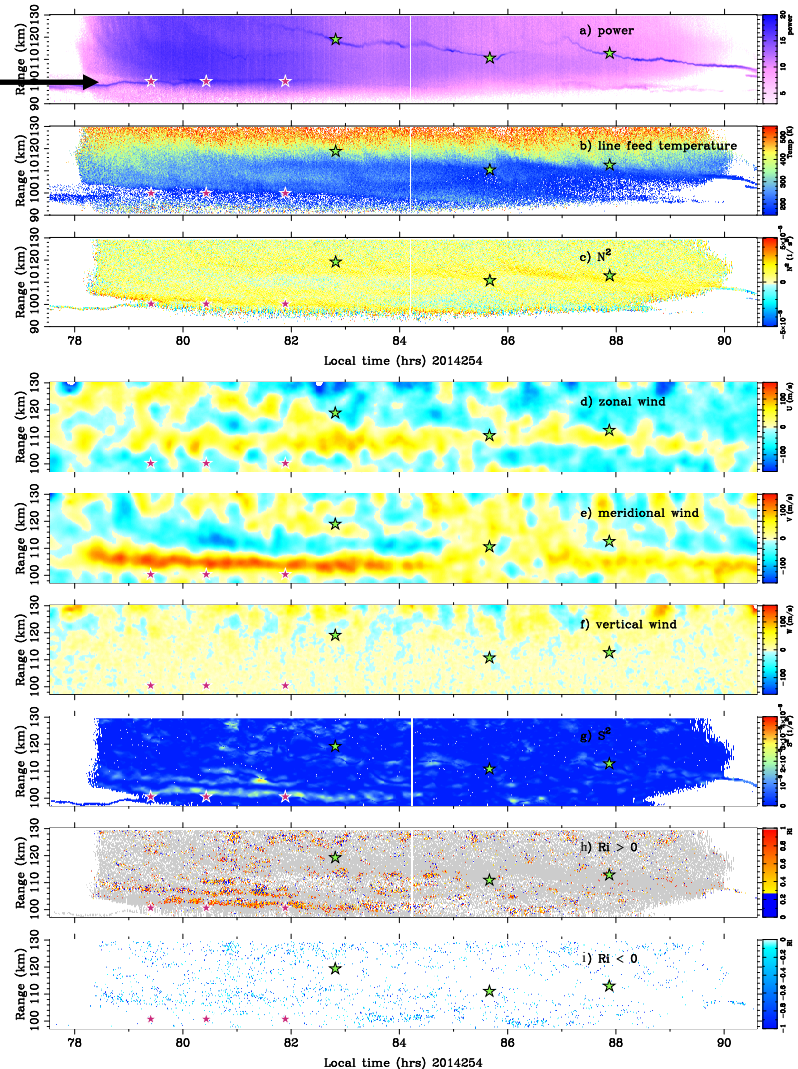
Zonal ( $u$ ) and meridional ( $v$ ) wind

# New mechanism compared with Arecibo data



- Horizontal winds should be in the north-west quadrant of the hodograph for altitudes below 110km over Arecibo.

The arrows on the hodograph mark altitudes:  
red at 97km,  
black at 105km, 115km, and 125km





- The meridional winds could have an important role in the formation of the lower metallic layers (near 100km) over the Caribbean and the East of US. Neutral wind measurements show cases of layer formation near 100 km, associated with strong meridional winds and weak zonal winds.
- A corrected layer formation mechanism is obtained for lower altitudes ( $h < 115$  km) for Arecibo when a complete magnetic field model ( $D = -12.5$  deg) is used. The meridional winds mechanism is reversed with respect to the original model (using  $D=0$ ). In the plots it means blue over yellow or southward over northward winds.
- The ratio of the contribution factors of the horizontal wind component at altitudes near 100km shows that strong meridional winds could overcome the effect of zonal winds (ratio~5 when using a complete magnetic field model vs ratio ~50 using a dipole model).
- A combination of the horizontal winds is considered to explain some of the lower layers observed in the data, where north-westward winds are present.