Why could there be a difference between FPI Doppler shifts and satellite drag measurements of thermospheric winds at high-latitudes?

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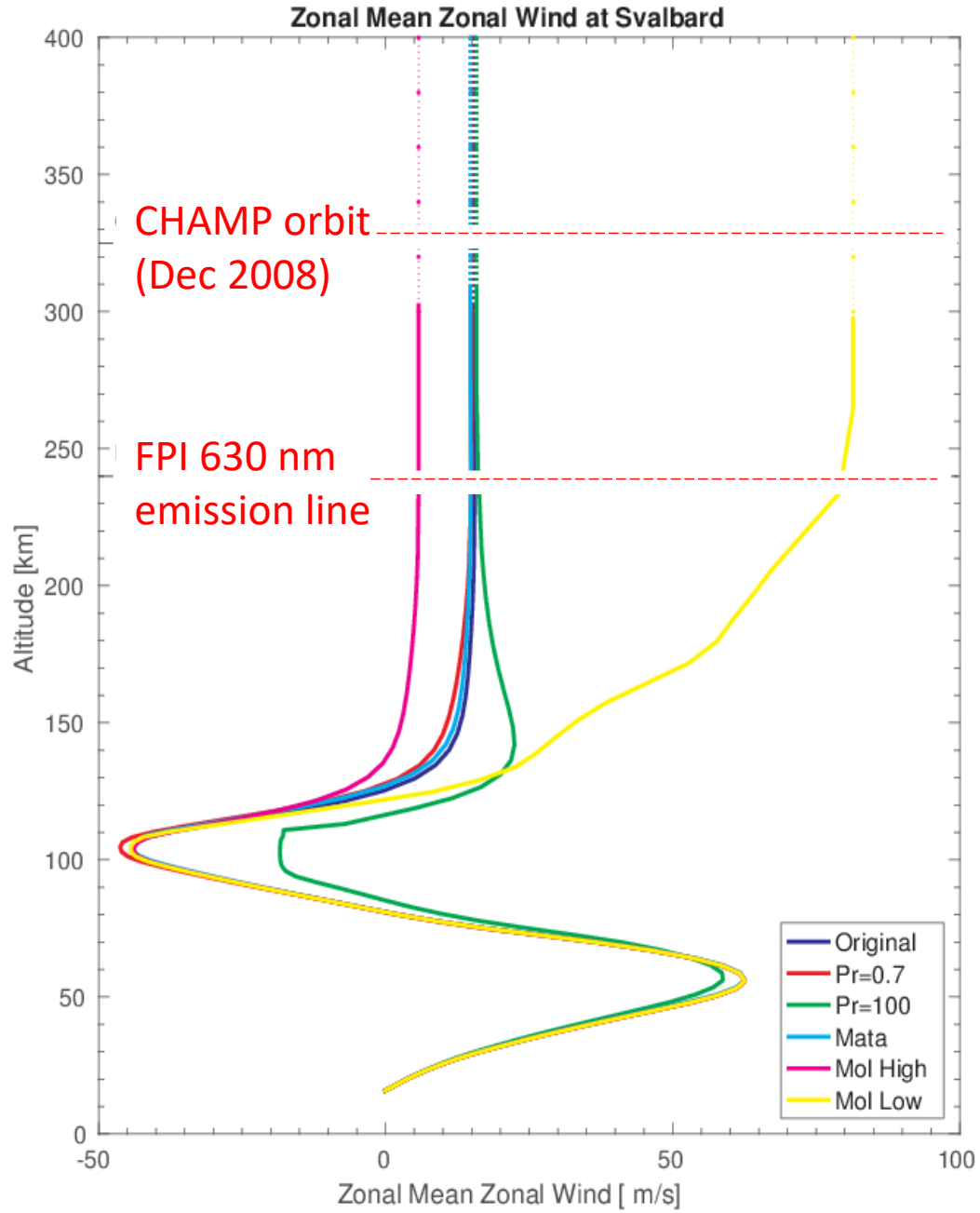
CEDAR Workshop 25th June; Thermospheric Dynamics Measurements 2021



Why should FPI winds be the same as CHAMP winds? What are the assumptions?

- Very high viscosity in the upper thermosphere > 200 km
- Molecular viscosity μ_m and turbulent viscosity μ_t are given by

$$\mu_t = \frac{P_r K_t}{c_p}$$

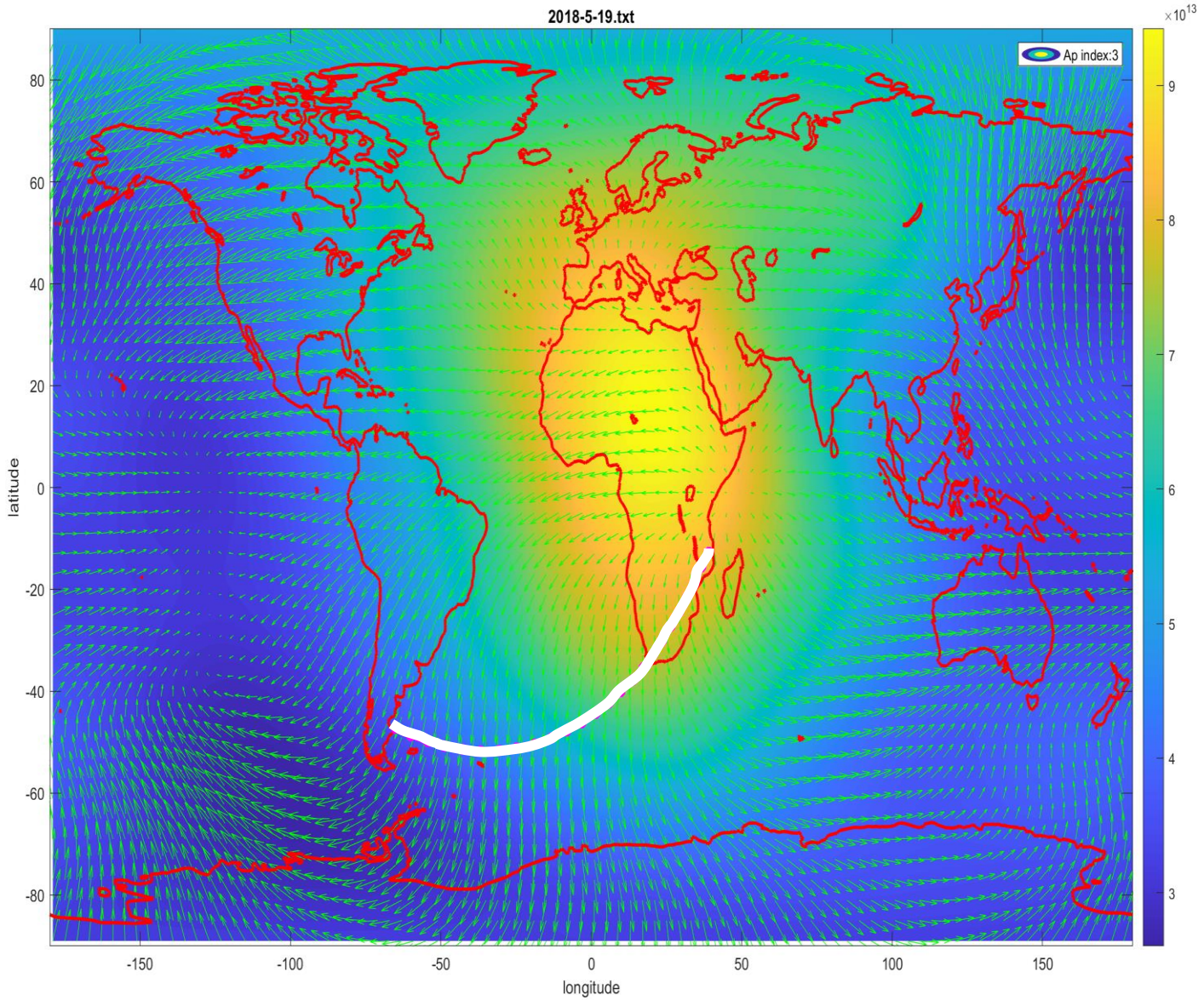
$$\mu_m = 4.5 \times 10^{-5} \left(\frac{T}{1000}\right)^{0.71} \quad [\mathrm{kg\ m^{-1}\ s^{-1}}]$$

- Molecular viscosity μ_m dominates for z > 100 km
- μ_m for O, O_2, N_2, He are similar

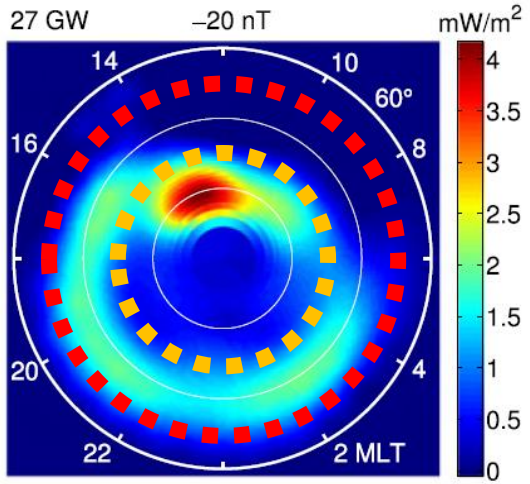
Height profile of CMAT2 zonal winds at Svalbard (Hood, PhD thesis 2018)

- **Satellites** - Global coverage, at all times
- **FPIs** – land-based, nighttime only

GOCE satellite – artist's impression (ESA - AOES Medialab)



HWM winds, NRLMSISE-00 mass densities and orbital path when the Ion-Neutral Mass Spectrometer was collecting data on the Phoenix CubeSat. From the QB50 mission on 19 May 2018. Mahammod – UCL MSci report (2021)

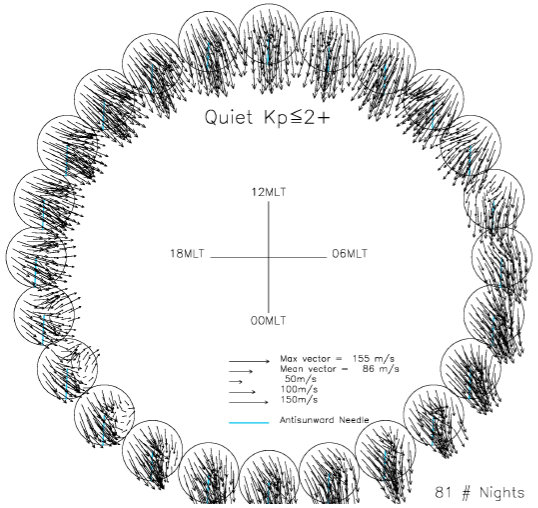


Adapted from Cosgrove + (2014)

UCL FPI network

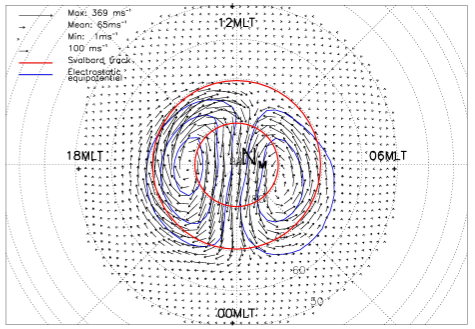
Svalbard FPI/SCANDI

KEOPS + Sodankylä FPIs



SCANDI neutral winds

Quiet - Kp ≤ 2+



SuperDARN plasma drifts

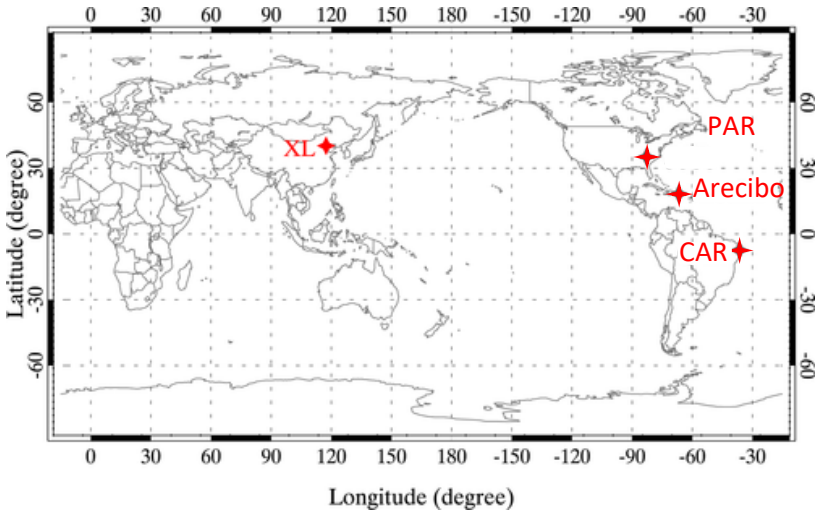
Ronksley PhD (2016)

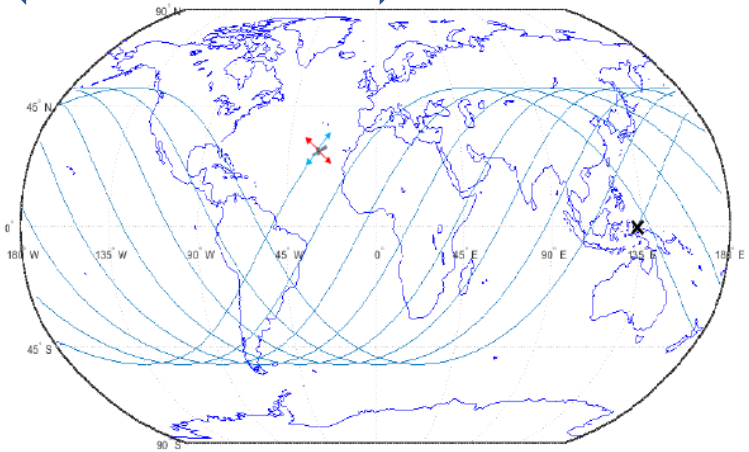
FPI Doppler shift

Thermospheric neutral winds, and density

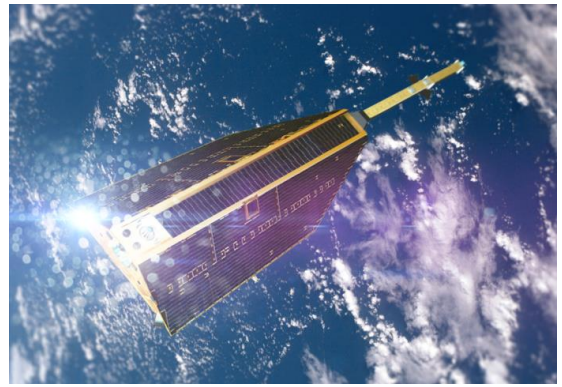
LEO satellite drag

Comparison of Thermospheric Winds Measured by GOCE and Ground-Based FPIs at Low and Middle Latitudes Jiang + (2021)



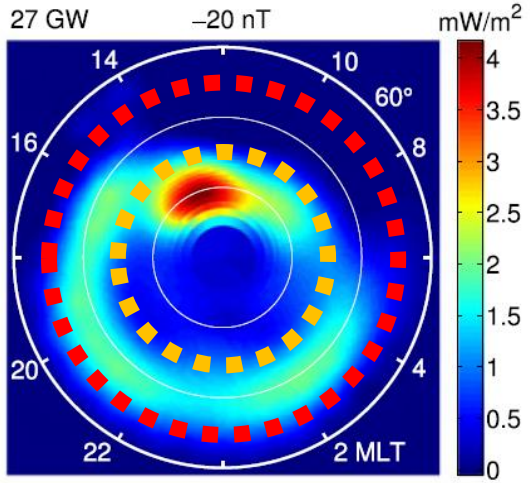


Forsyth MSci thesis (2020)



CHAMP satellite

(artist's impression – Tiouraren)



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UCL FPI network

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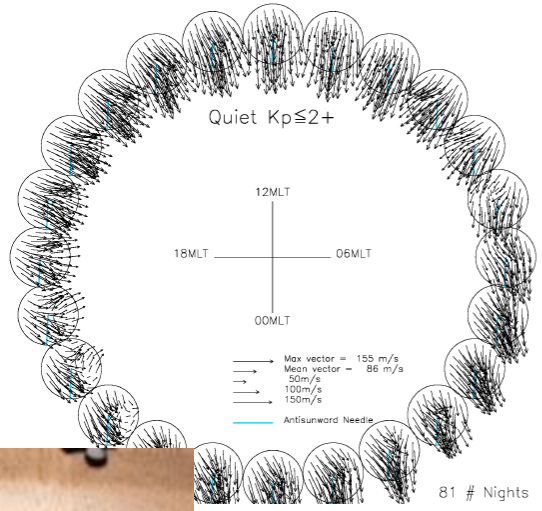
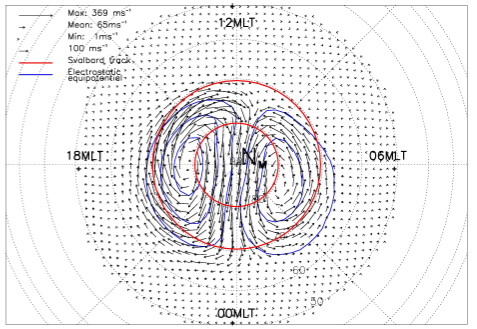


NDI neutral winds

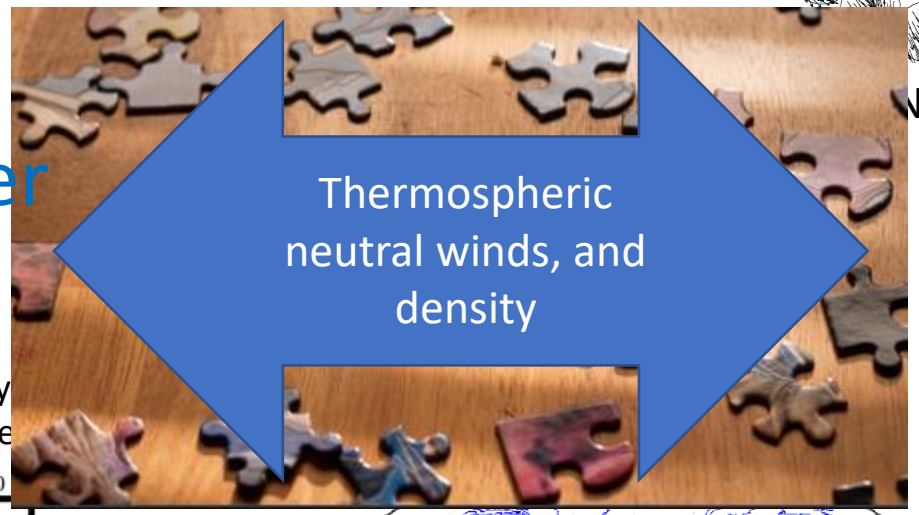
Quiet - Kp ≤ 2+



SuperDARN plasma drifts

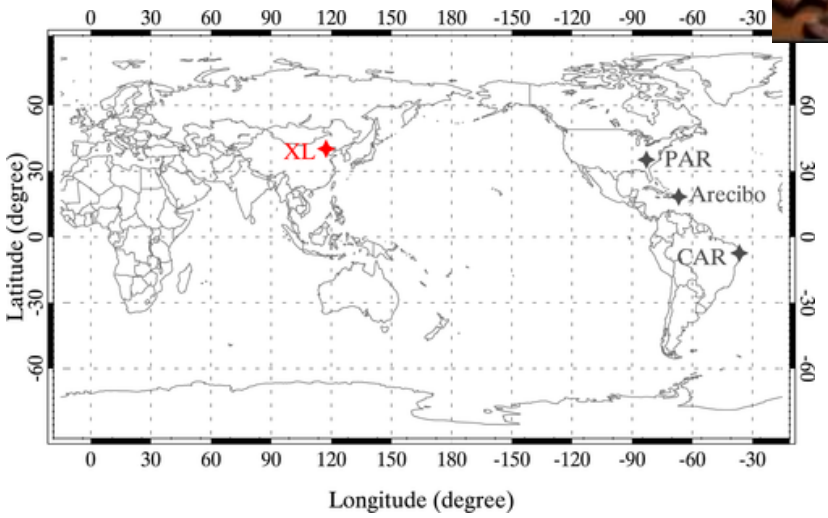
Ronksley PhD (2016)

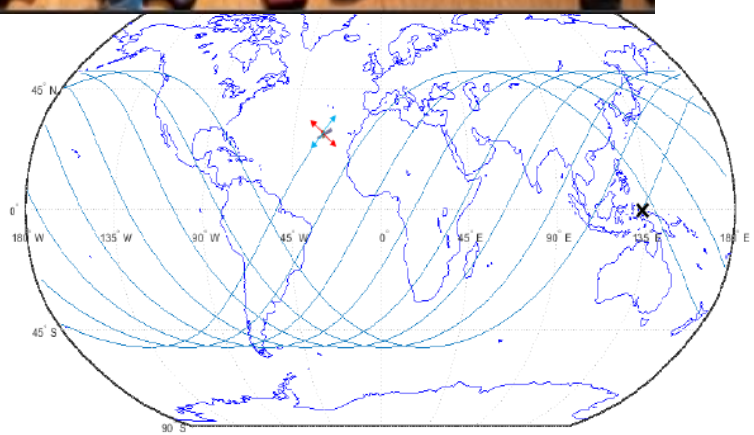
FPI Doppler shift



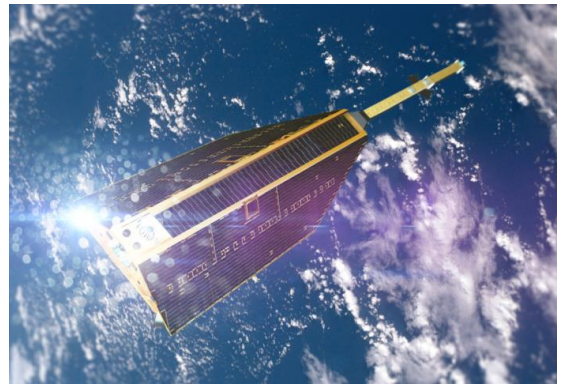
LEO satellite drag

Comparison of Thermospheric Winds Measured by and Ground-Based FPIs at Low and Middle Latitude





Forsyth MSci thesis (2020)



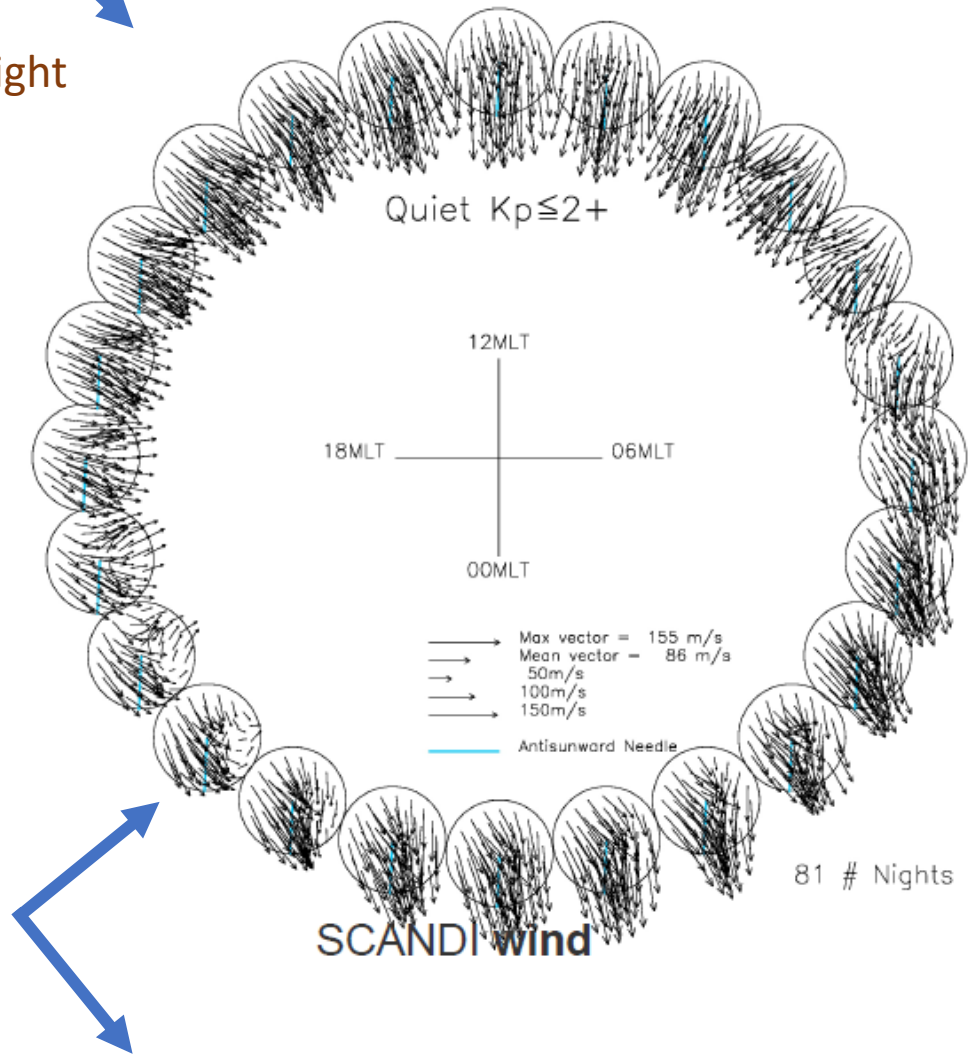
CHAMP satellite

(artist's impression – Tiouraren)

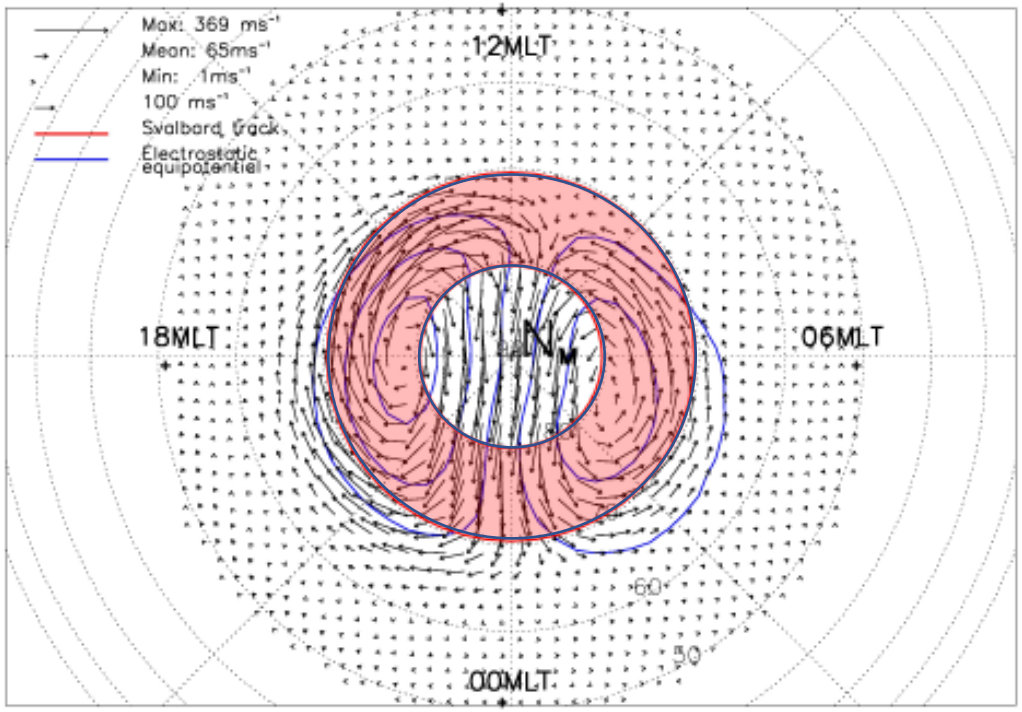
FPI Doppler shifts

FPI line-of-sight looking North

FPI line-of-sight looking East

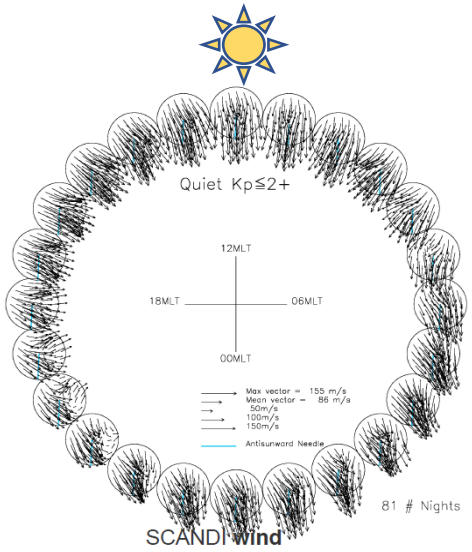


Quiet - Kp ≤ 2+



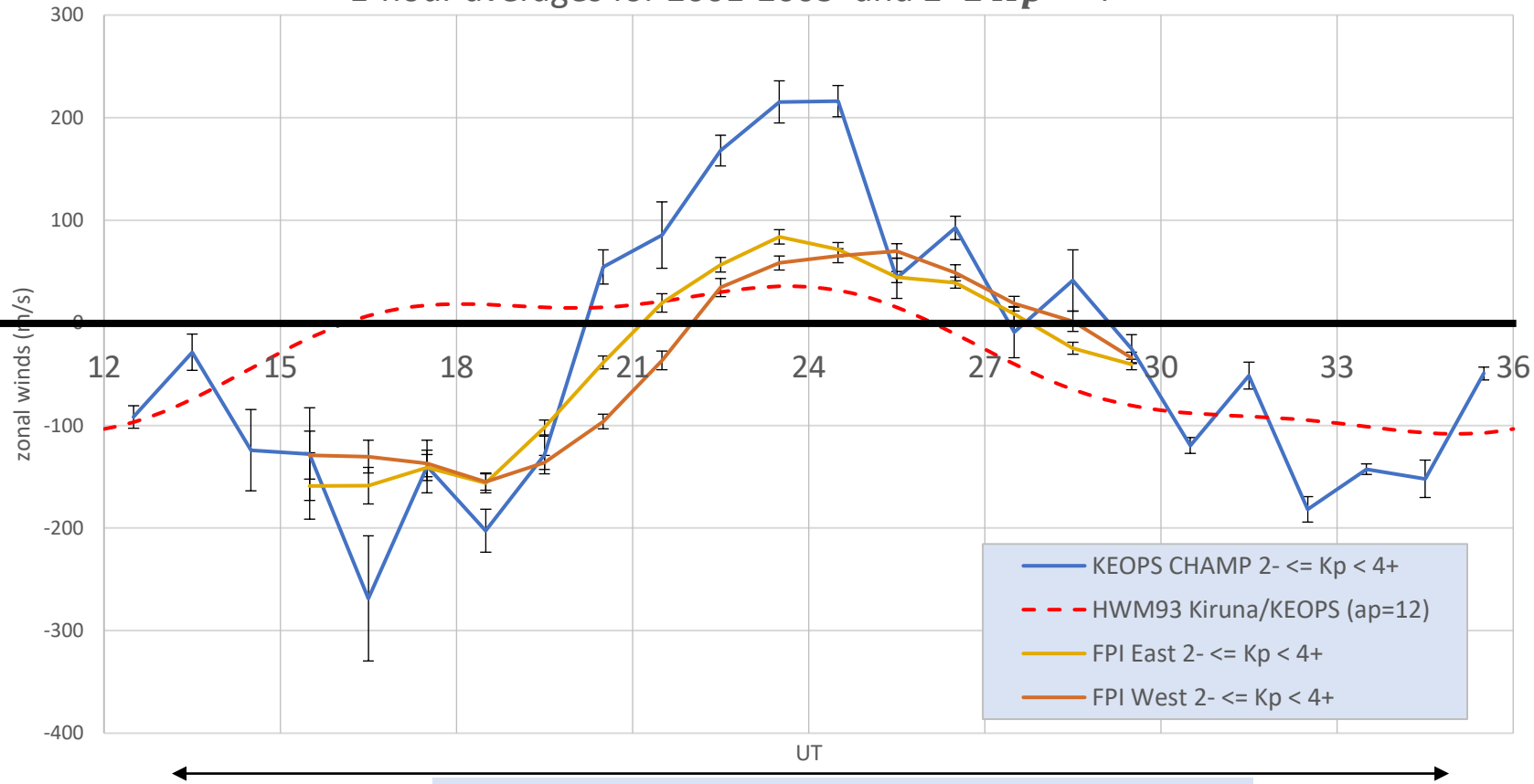
SuperDARN **plasma drift**

FPI Doppler shifts

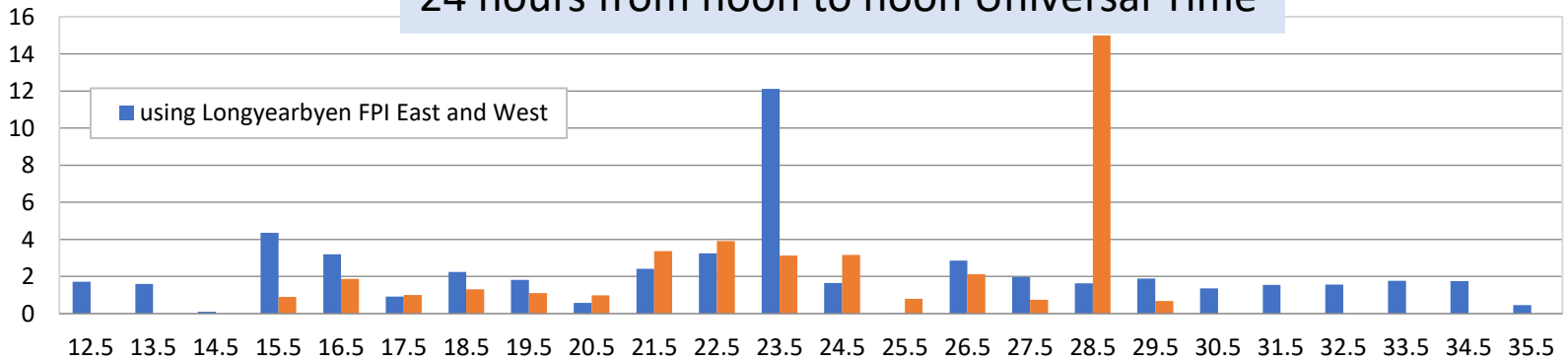


zero

Zonal (Eastward) winds at KEOPS/Kiruna: CHAMP crosswind vector component versus FPI and HWM93
1-hour averages for 2001-2003 and 2- ≤ Kp < 4+

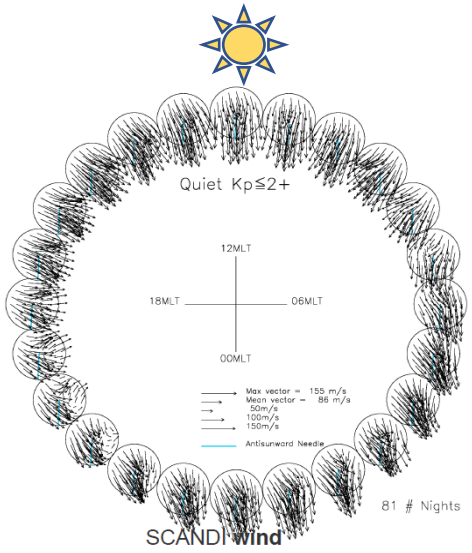


24 hours from noon to noon Universal Time



UT dependence of ratio of absolute CHAMP/FPI combined East-West
2- ≤ Kp < 4+
Aruliah + (2019)

FPI Doppler shifts



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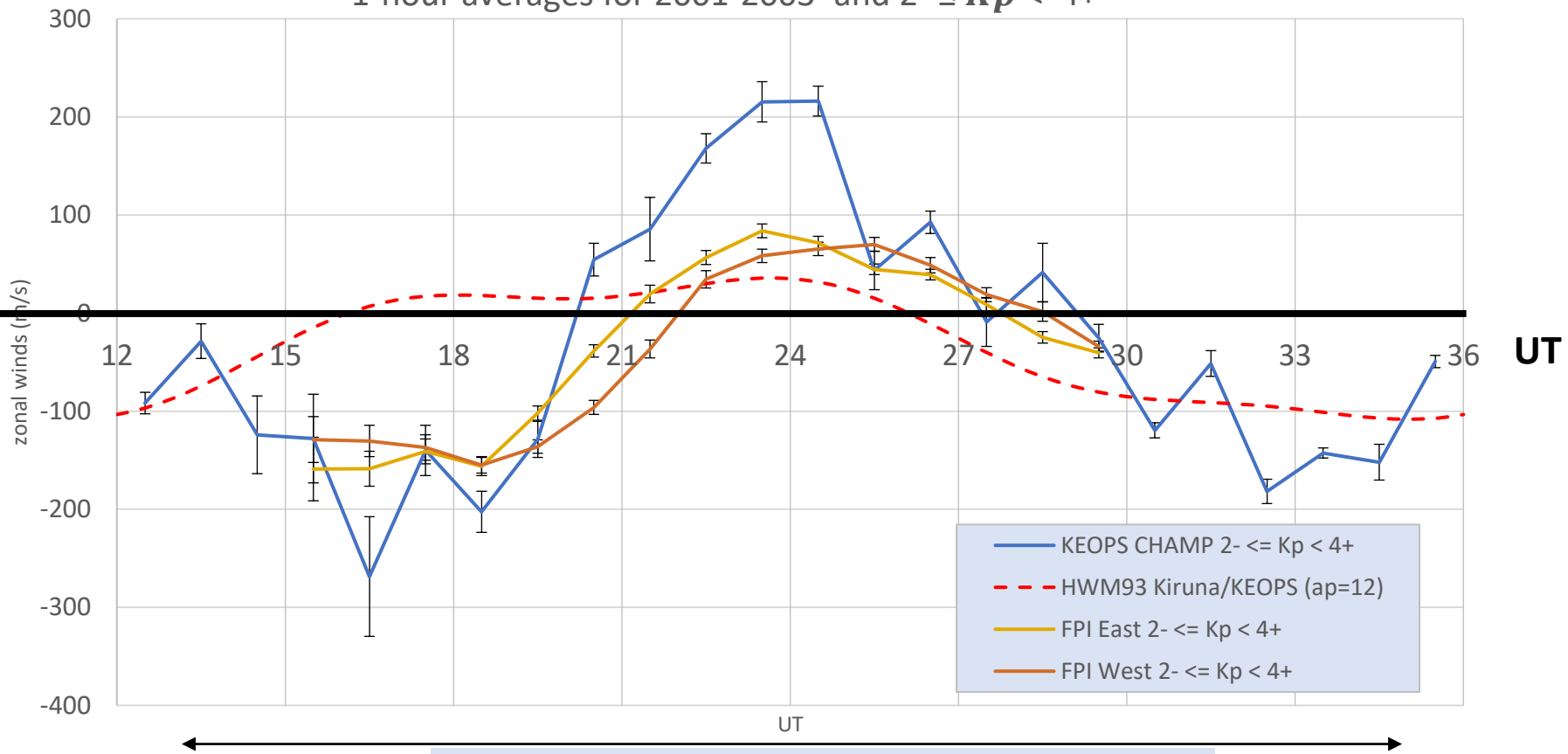
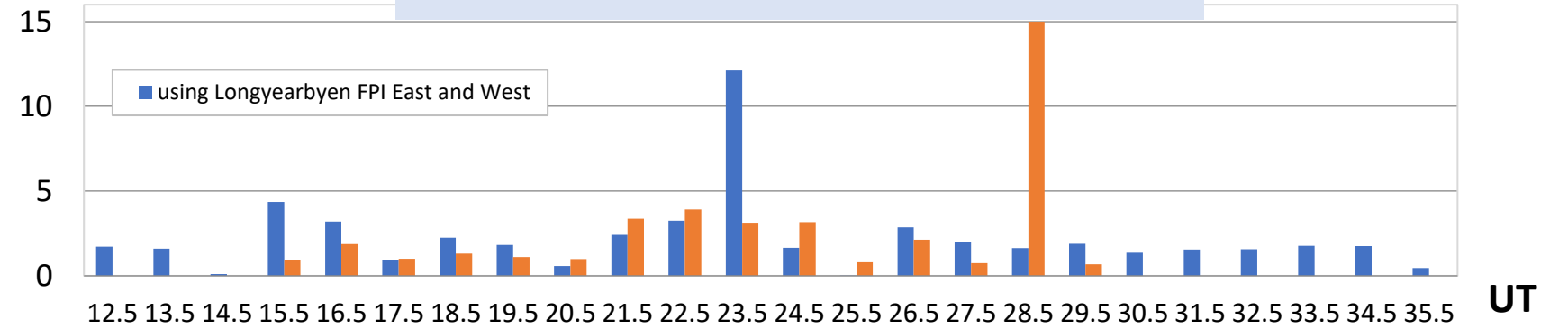


UT

24 hours from noon to noon Universal Time

Jiang + (2020) for mid- and low-latitude FPIs versus GOCE winds found:

$$1.37 < \frac{U_{GOCE}}{U_{FPI}} < 1.69$$

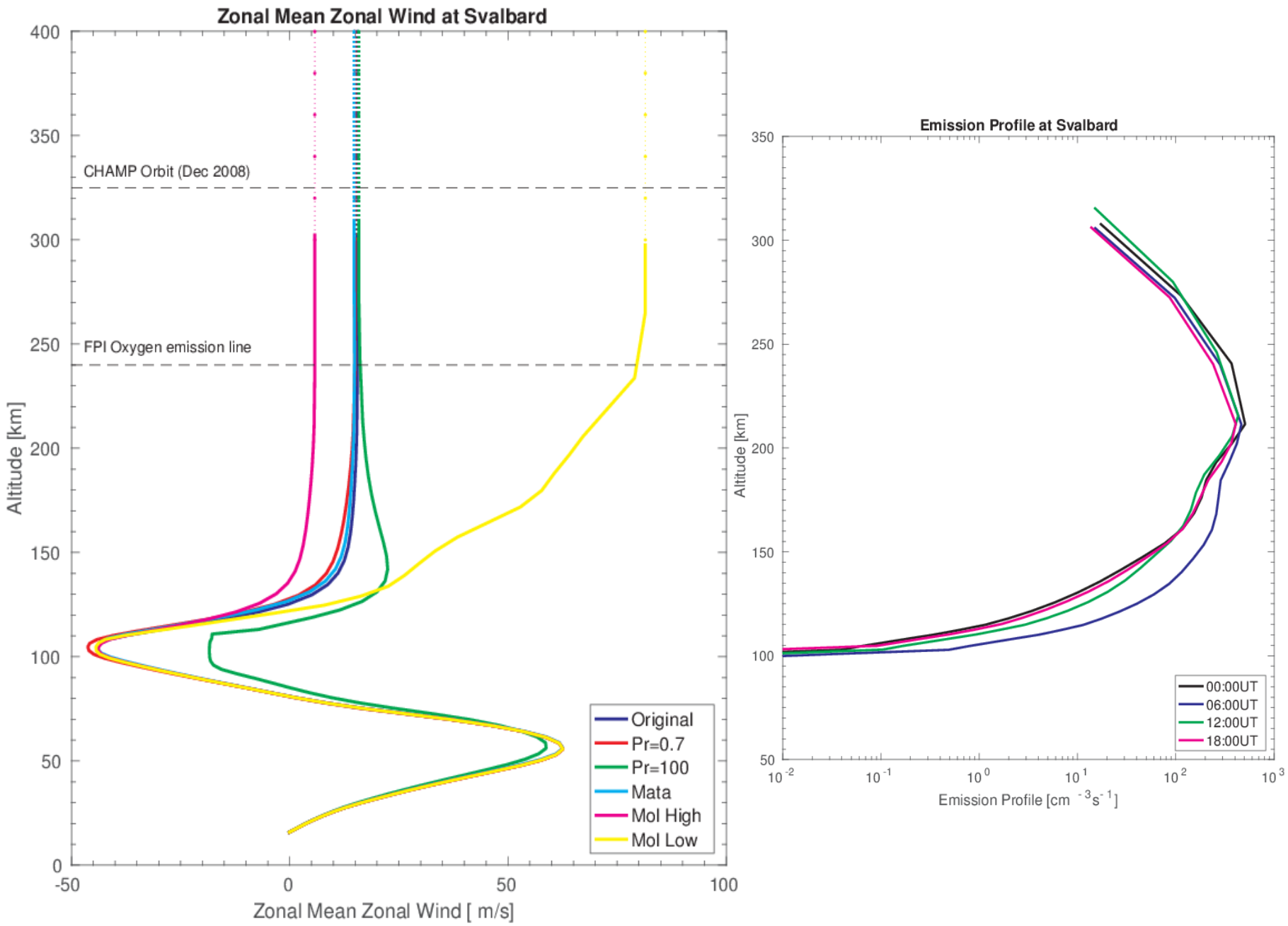


UT dependence of ratio of absolute CHAMP/FPI combined East-West
2- ≤ Kp < 4+
Aruliah + (2019)

Challenge to high viscosity assumption by Vadas & Crowley (2017)

Ray tracing 10 Travelling Ionospheric Disturbances with an ionospheric sounder (TIDDBIT, Wallops Island)
+
Sounding rocket measured energy dumped in the neutral winds ~325 km

Conventional dissipative theory predicts all AGWs dispersed by scale height below rocket measurement
So viscosity is not so large?

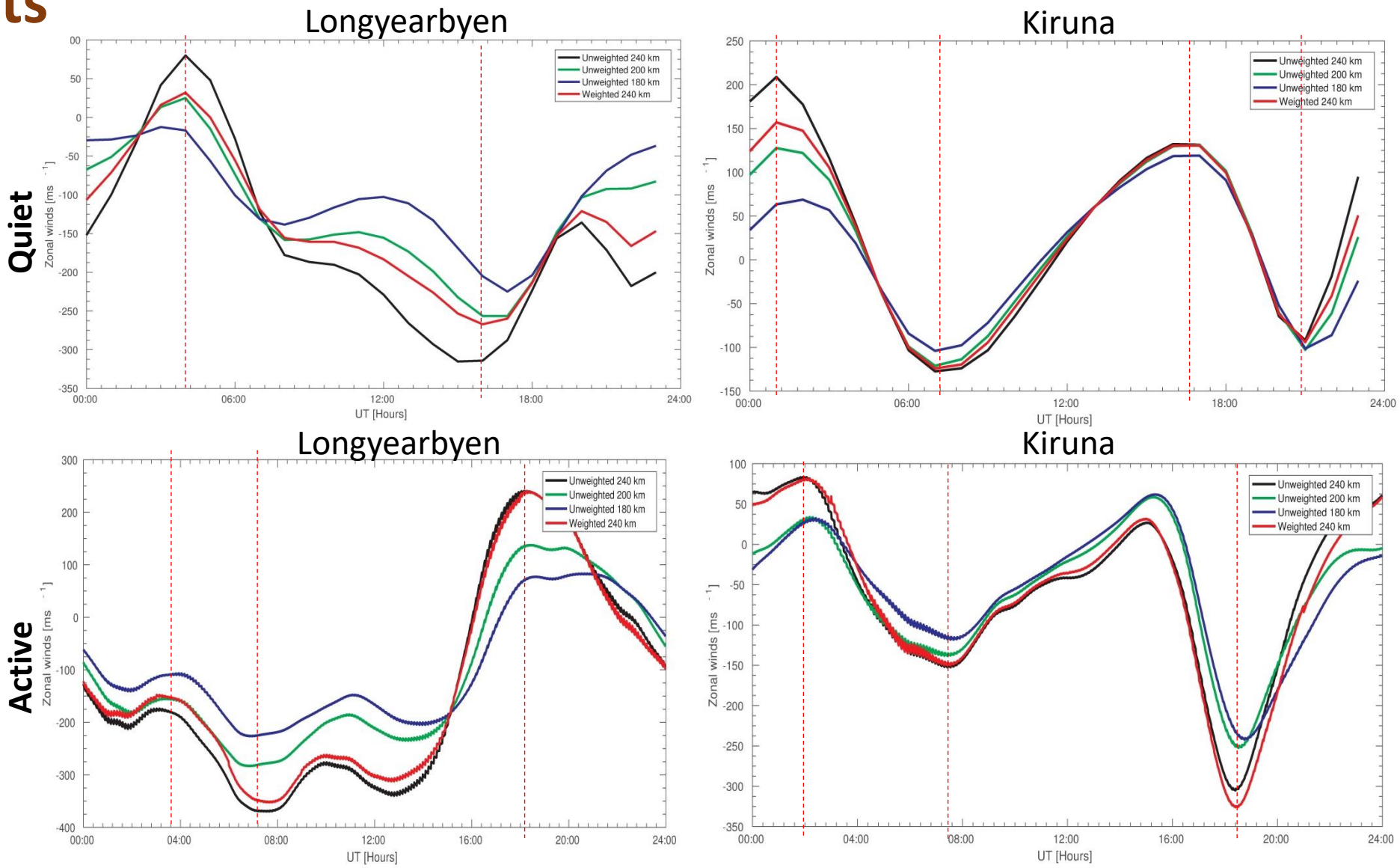


left: height profile of CMAT2 zonal winds at Svalbard. Right: height profile of the red line emission intensity profile from the Vlasov et al (2005) model.

FPI Doppler shifts

CMAT2 physical model showing neutral winds at 180, 200 and 240 km. Compare with the weighted average wind if the 630 nm peak is at 240 km (i.e compare the red and black lines)

Also to be considered – aerosol scattering – reduced wind measurements (Harding + (2017)



top: CMAT2 zonally averaged zonal winds for a quiet day on 1st December 2007 at Longyearbyen (left) and Kiruna (right) for the winds at 180, 200 and 240km for comparison with the height integrated winds weighted using an emission intensity profile from the Vlasov et al (2005) model. Bottom: the same for active conditions on 20th March 2015. (Aruliah +, 2019)

Atmospheric drag

Graph of forces acting on a satellite against its altitude Montenbruck and Gill (2000).

(Not to scale)

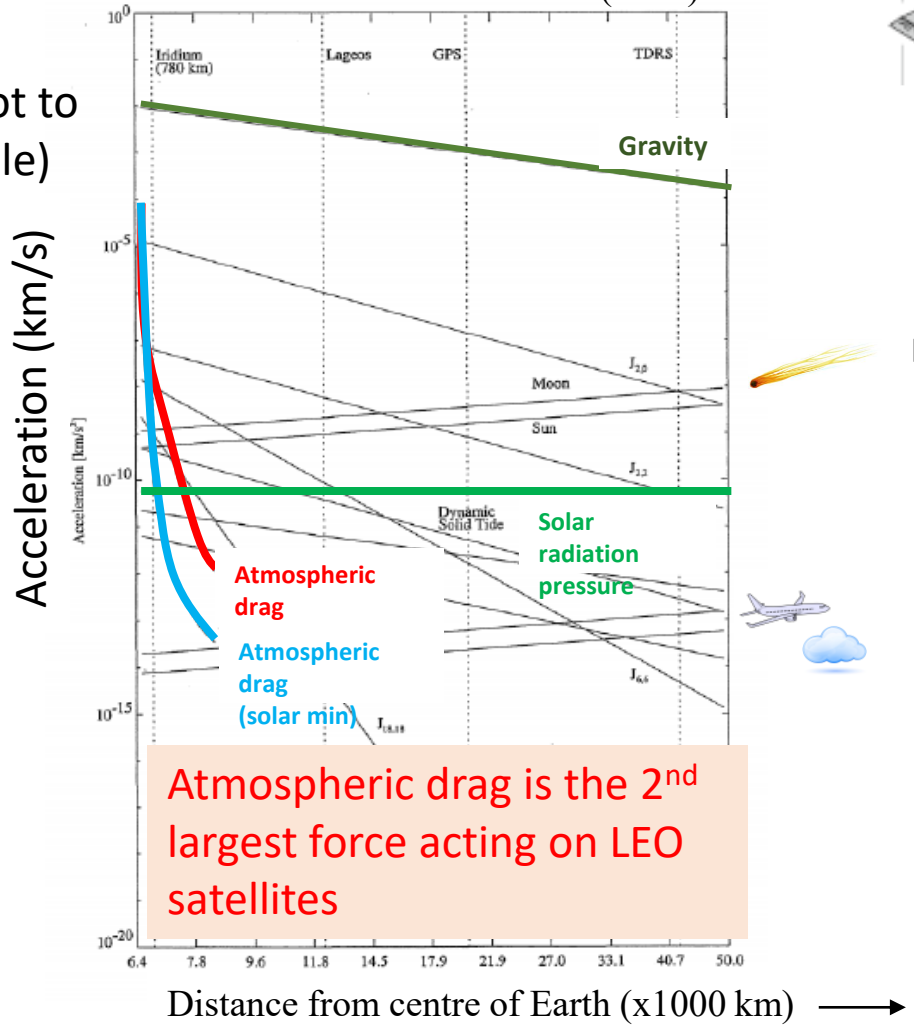


Figure 2.16: A graph of forces acting on a satellite against its altitude, courtesy Mon-

Atmospheric drag is the 2nd largest force acting on LEO satellites

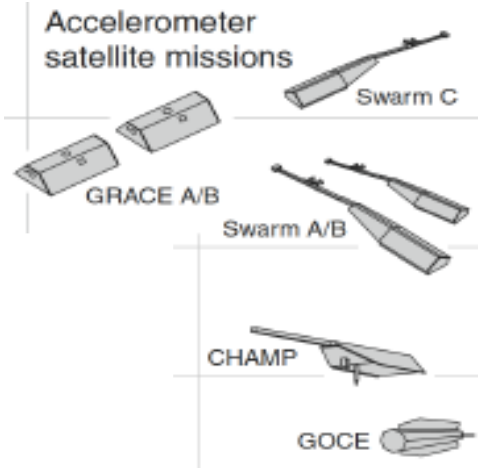
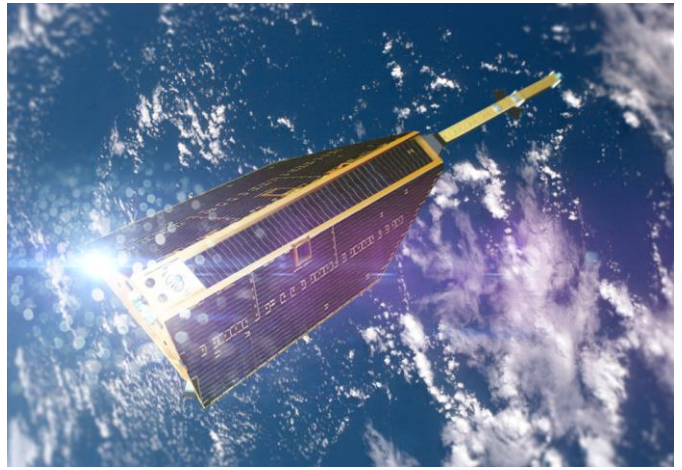


Image from Doornbos (2011)



CHAMP satellite (artist's impression – Tiouraren)
Triaxial accelerometers

Thermospheric wind-squared

$$\boldsymbol{a}_{drag} = -\frac{1}{2}\rho C_d \frac{A_{ref}}{m} V_{rel}^2 \boldsymbol{e}_v$$

Atmospheric density

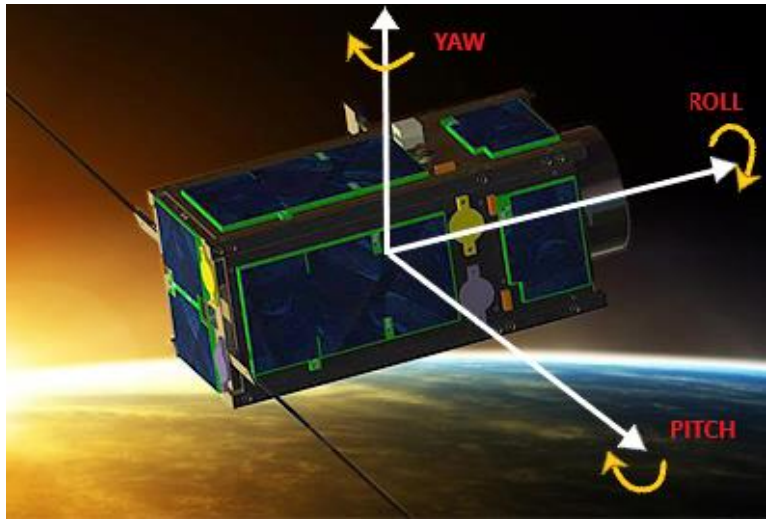
Drag coefficient

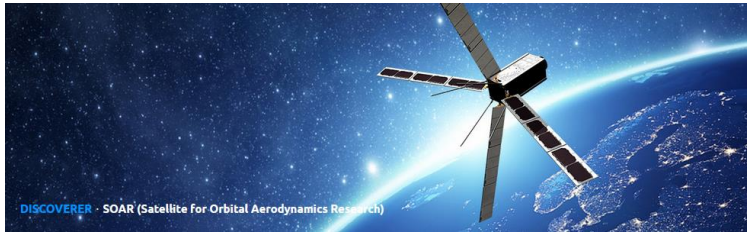
Cross-sectional area/satellite mass

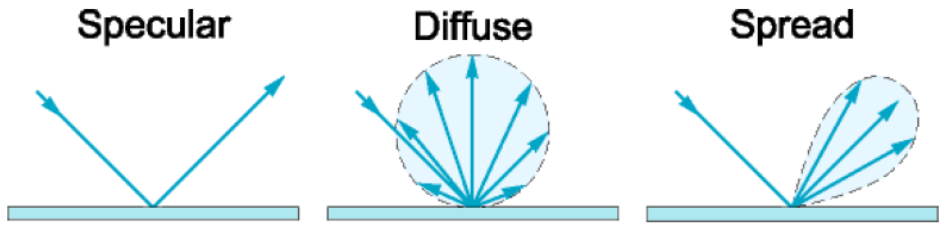
Atmospheric drag ↔ Fluid dynamics Up to~600km

Ballistic particle trajectories > 600 km altitude

Atmospheric drag

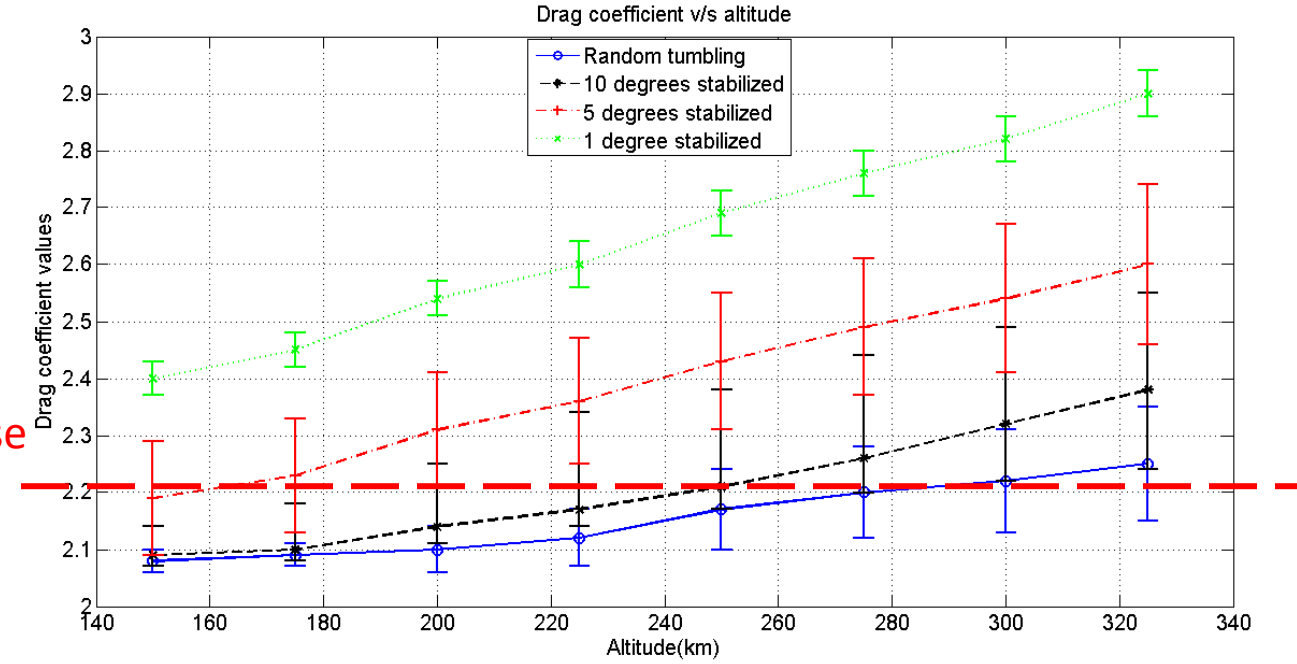






Specular, diffuse, and spread reflection from a surface.

Aspect angle to the cross-wind



Jacchia chose
Cd = 2.2

Ray – UCL summer student report 2015

Thermospheric wind-squared

$$\boldsymbol{a_{drag}} = -\frac{1}{2}\rho C_d \frac{A_{ref}}{m} V_{rel}^2 \boldsymbol{e_v}$$

Atmospheric density

Drag coefficient

Cross-sectional area/satellite mass

Finally - Why do the neutral winds matter?

- Energy budget and momentum transfer depend on $\underline{V_i} - \underline{U_n}$
- Vertical and horizontal coupling, and continuity of mass, energy, composition
- Electric fields are in the frame of reference of the neutral winds
- Sq current systems at low and mid-latitudes are due to neutral winds crossing $\underline{\boldsymbol{B}}$
- the same Satellite Drag equation is used to derive thermospheric density
- Satellites provide global coverage at all times, so a heavy influence on empirical models