National Institute of Information and Communications Technology

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Space Weather Forecast Operation & Research for Small Satellites

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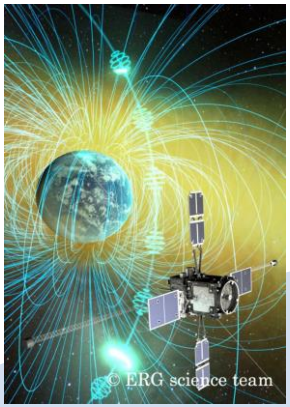
Size of Satellites

Michibiki
http://qzss.go.jp

Arase
http://www.isas.jaxa.jp/missions/spacecraft/current/erg.html



Maido-1
https://sohla.com/maido.html
0.5mx 0.5mx 0.5m, 55kg

Medium/large
6.2mx3.1mx2.9m, 4,100kg

Small
1.5mx1.5mx2.7m, 355kg

Nano

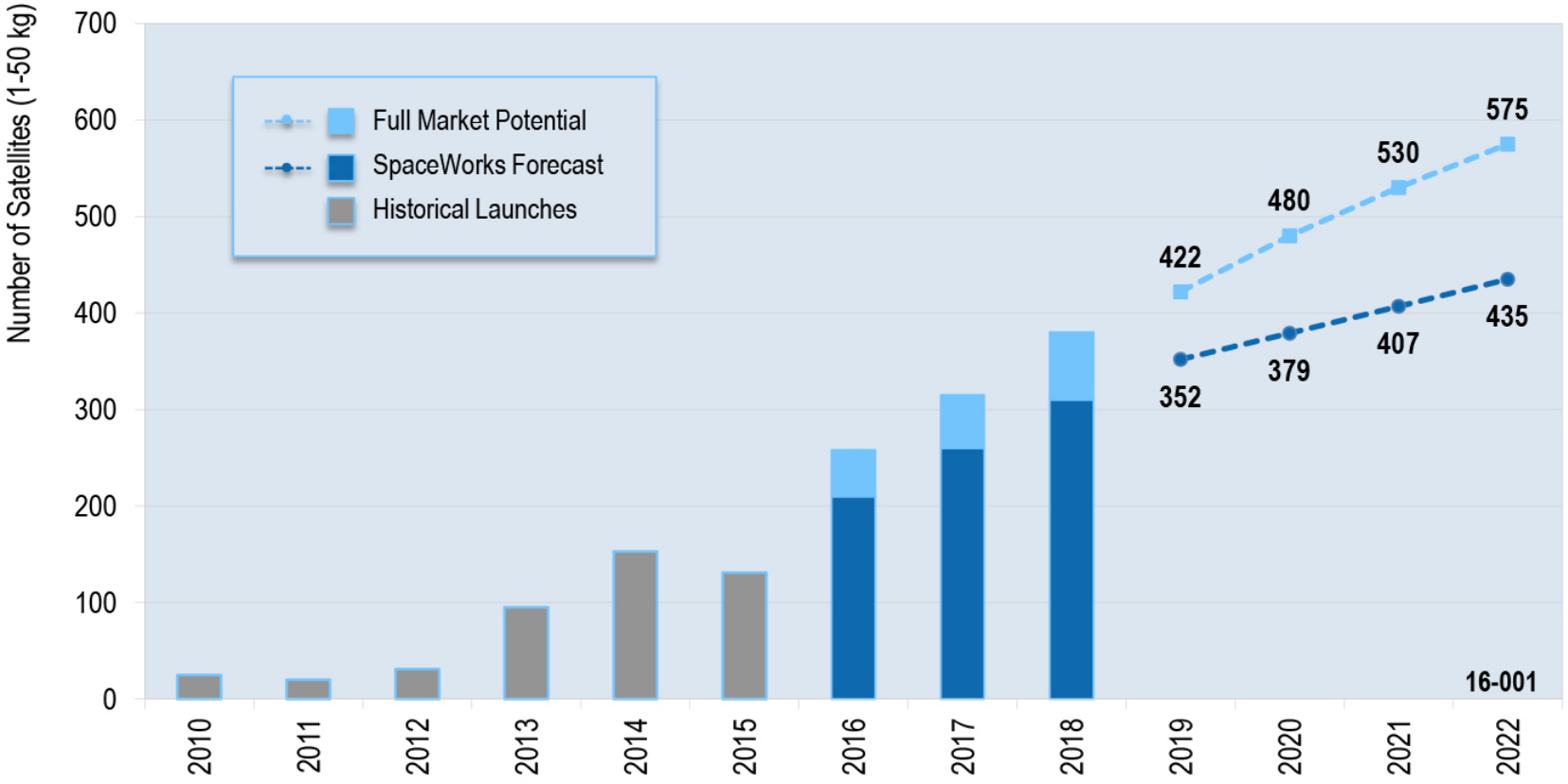
Cubesat
http://www.cubesat.org/
0.1mx0.1mx0.1m 1.33kg

Femto

PCBSat 0.35mx0.35mx0.004m
https://www.youtube.com/watch?v=yl1AI_2c9cM

Estimating Number of Nano/microsatellites

Projections based on announced and future plans of developers and programs indicate as many as 3,000 nano/microsatellites will require a launch from 2016 through 2022

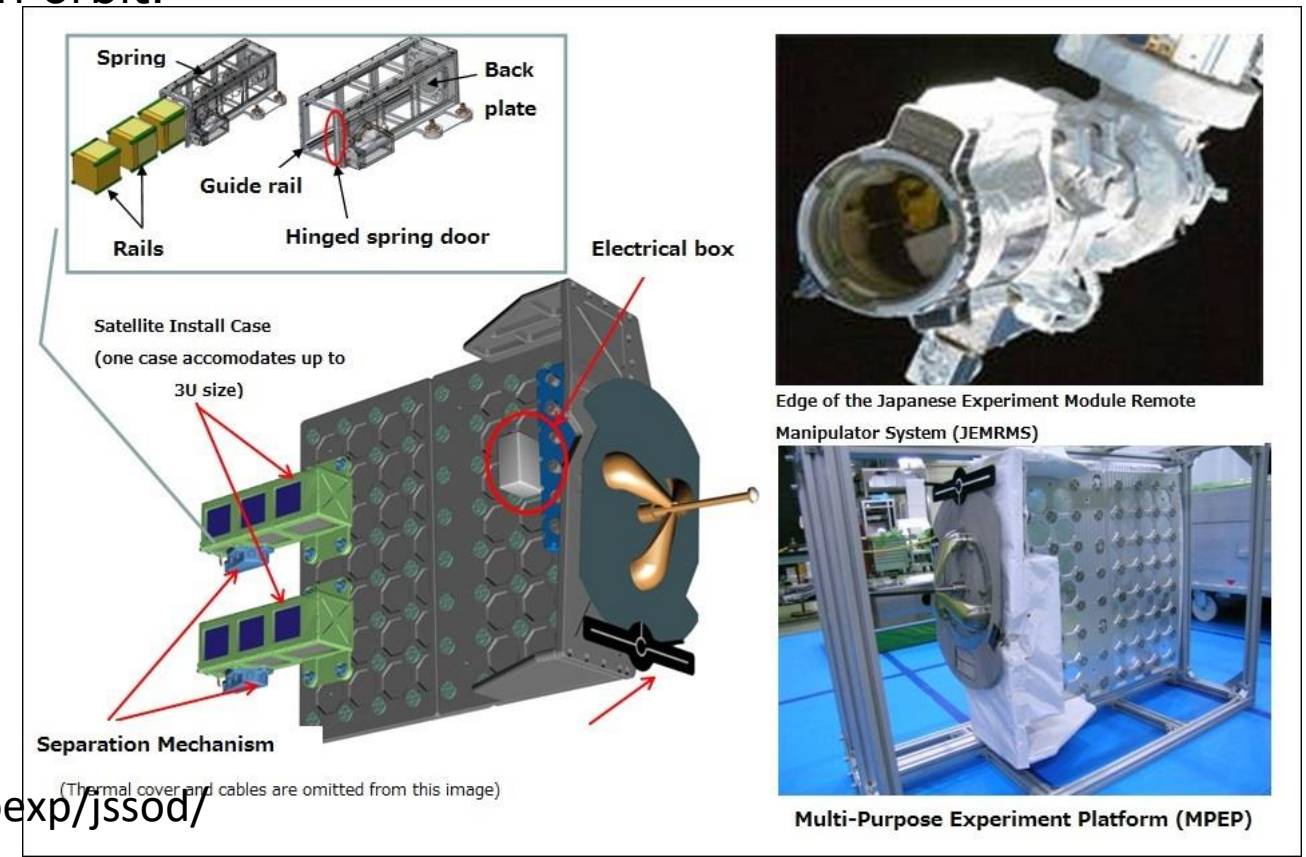


The 2016 Full Market Potential dataset is a combination of publically announced launch intentions, market research, and qualitative/quantitative assessments to account for future activities and programs.
The 2016 SpaceWorks Forecast dataset reflects SpaceWorks' expert value judgment on the likely market outcome.

Source: 2016 Nano/Microsatellite Market Assessment report by SpaceWorks Enterprises, Inc.

Small Satellites Projects in Japan

- JEM Small Satellite Orbital Deployer (J-SSOD) by JAXA
  - JEM Small Satellite Orbital Deployer (J-SSOD) is a mechanism for deploying small satellites designed in accordance with CubeSat design specification (10cm×10cm×10cm) that transfers the satellites from the Japanese Experiment Module Kibo's airlock to space environment and releases them on orbit.



http://iss.jaxa.jp/en/kiboexp/jssod/

Air drag on LEO

- Most of small satellites are planed to launch on low Earth orbit(LEO).
  - Relatively lower power for communication
  - Constellation compensates the limit of sight area
- Air drag is more critical factor for small satellites on LEO
  - Inertia is smaller than large satellites
  - LEO satellites are affected on air drag than GEO/MEO satellites

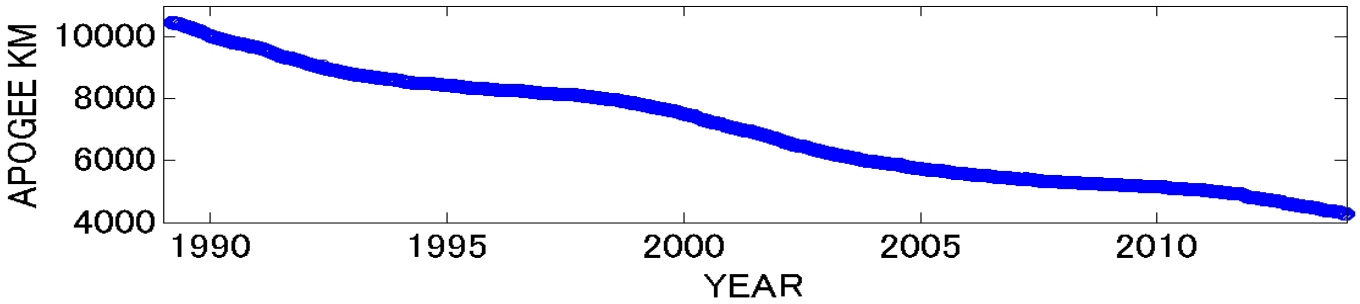
Critical hazardous on satellite operation

- ASCA
  - Weight: 450kg, Inclination: 31 deg
  - Launched on Feb. 20, 1993
  - ASCA had observed more than 2,000 planets with X-ray telescope
- Solar flare on July 14, 2000 (Bastille event) generated air expansion which made unexpected air drag to ASCA
- Attitude was uncontrolled and observation was unavailable at the height of 400km
- Recovering trial had been continued but finished the operation and dropped in the atmosphere on March 2, 2001

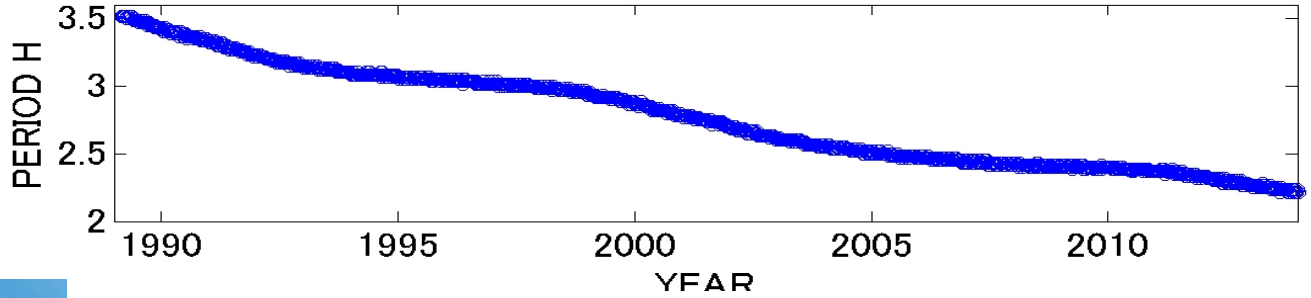
An example of air drag –AKEBONO--

The height of apogee decreases from 10,500km launching on 1989 to 4,000km on 2015.

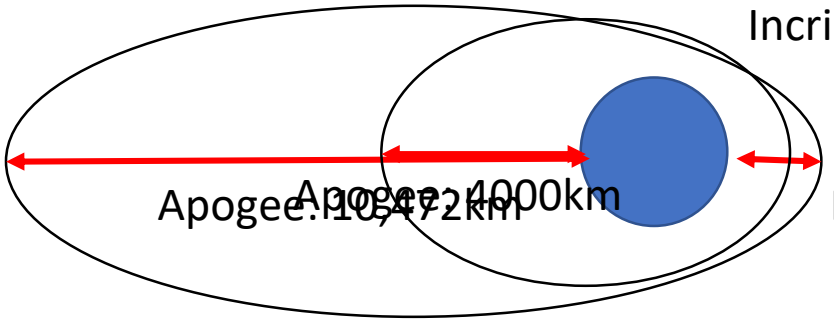
Apogee
（Unit：km）



Cycle period
（Unit：Hour）

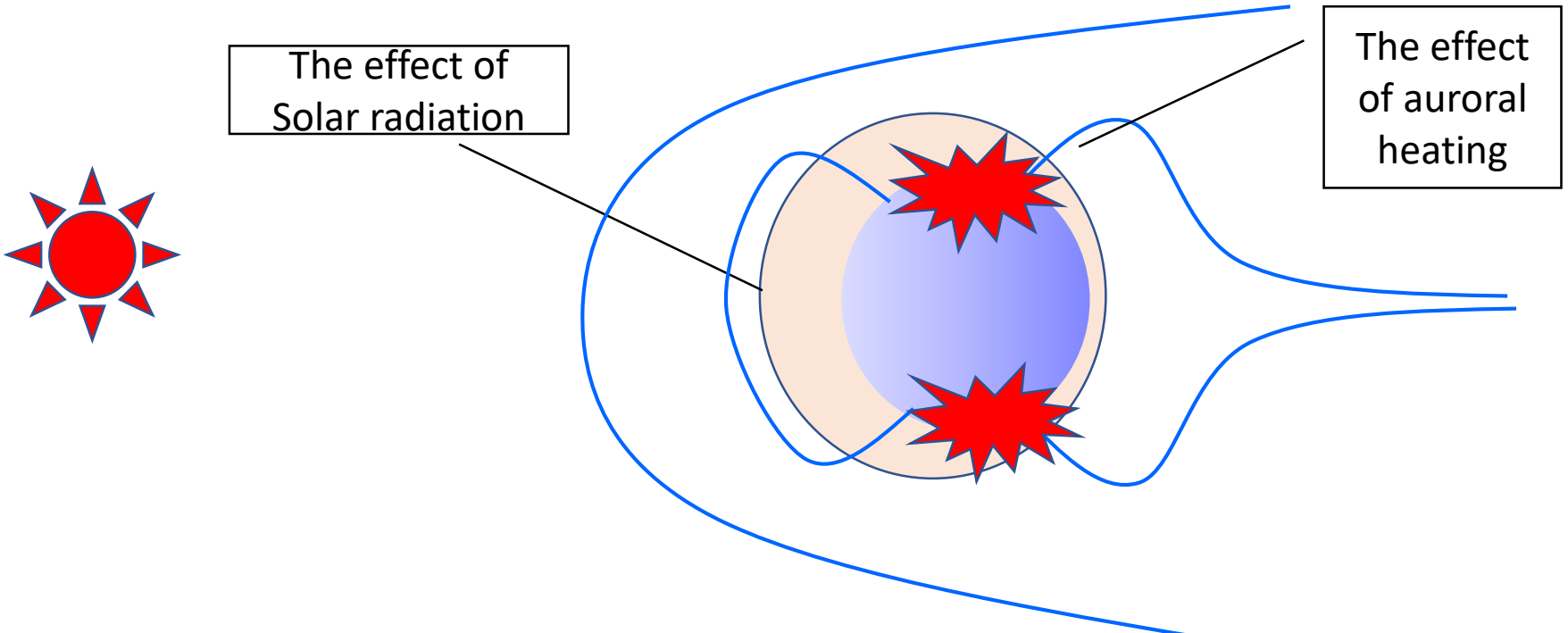


AKEBONO Weight: 295kg



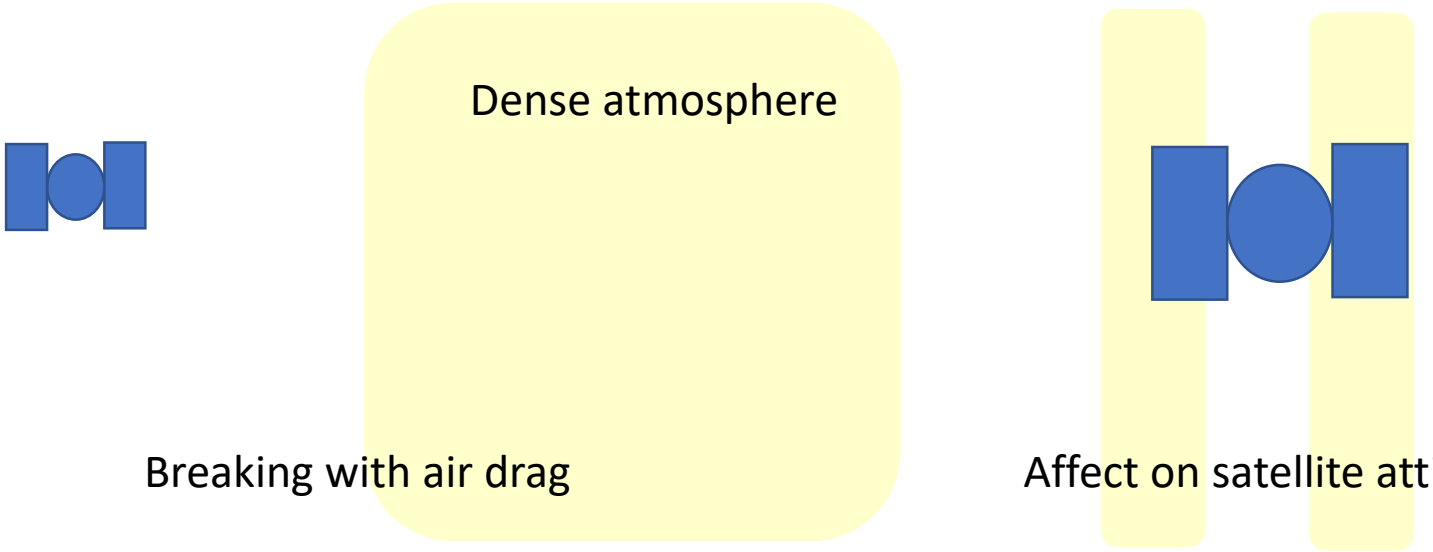
Characteristics of Air drag

- The effect of Solar radiation
  - Equator region is significantly affected
  - Large scale, slow variation and no fine structure
- The effect of auroral heating
  - Polar region is significantly affected
  - Small scale, rapid variation and small scale structure



Affect on satellites

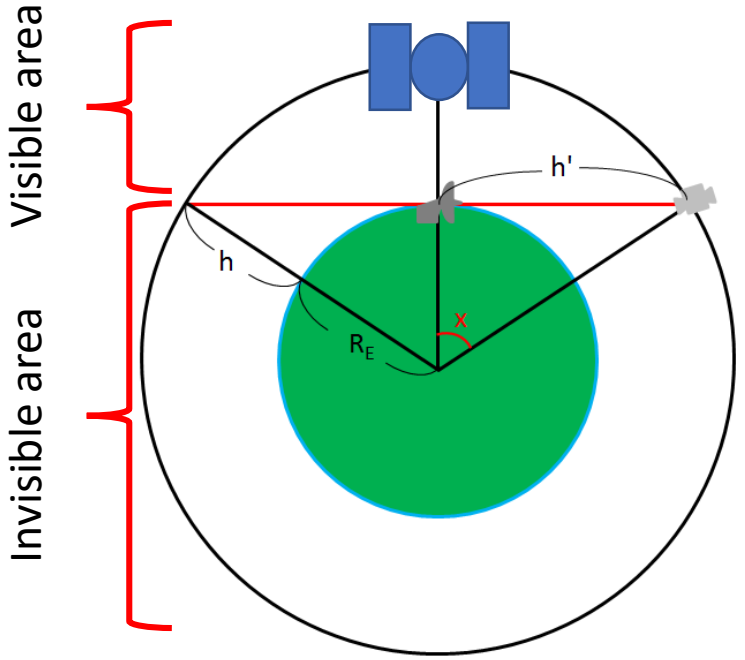
- Delay of cycle period
  - Breaking by air drag makes the cycle period delayed.
- Affect on satellite attitude
  - Small scale perturbation of air desity distribution makes the satellite attitude unstable.



Delay of cycle period

- A simple estimation of delay of cycle period by air drag
  - polar orbit with 200km of height(h), period T:1.467hour
  - only one satellite tracking with aperture D: 10m and uses X-Band (8GHz; wavelength λ 0.0375m)
  - this system can track the satellite by 0 deg of elevation angle.
  - half value width of antenna beam θ is calculated as follows

    $\theta \approx 70\ \lambda/a = 70\ 0.0375/10 \approx 0.2625°$
  - Using simple calculation from these condition, the atmospheric density should increase four times as dense as usual if the satellite run off the antenna beam θ.



Vertical winds near aurora

- It is known that high velocity vertical winds are observed in thermosphere near auroral arc. In some cases it reaches 100m/s which is comparable with horizontal wind (~500m/s)

- This vertical winds are driven by auroral heating and make air explosion which increases air drag on polar satellites.
- The vertical winds have small scale structure horizontally (~100km) and varies rapidly.

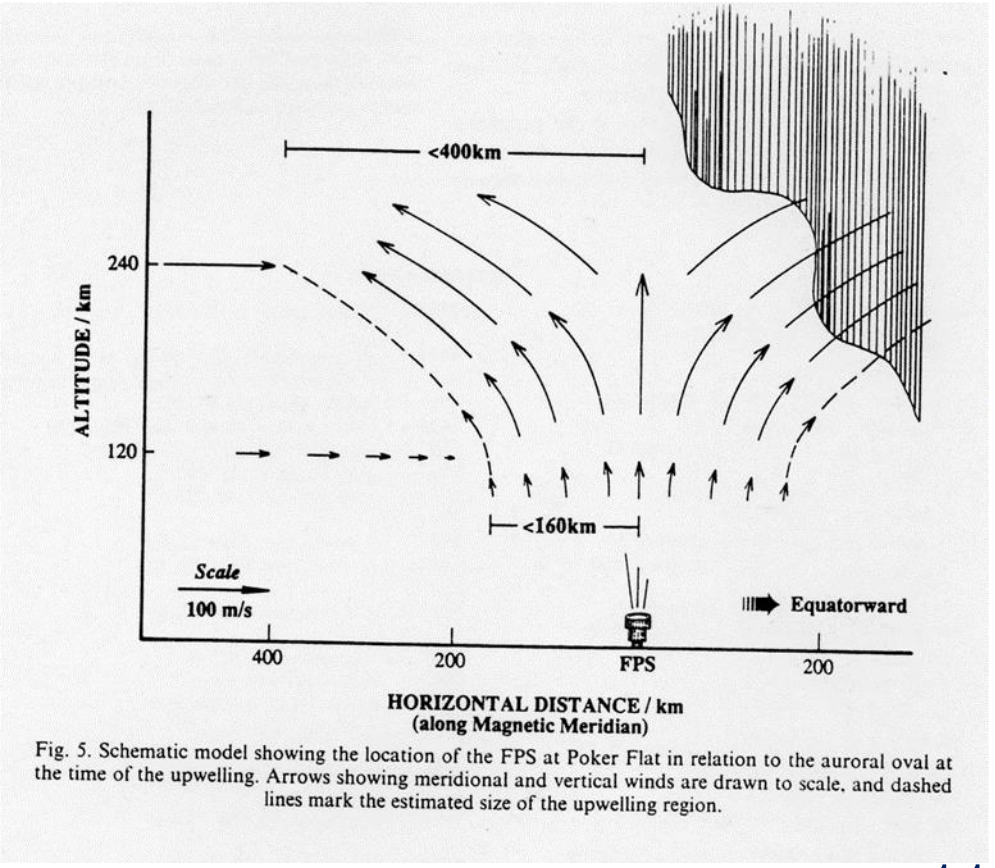


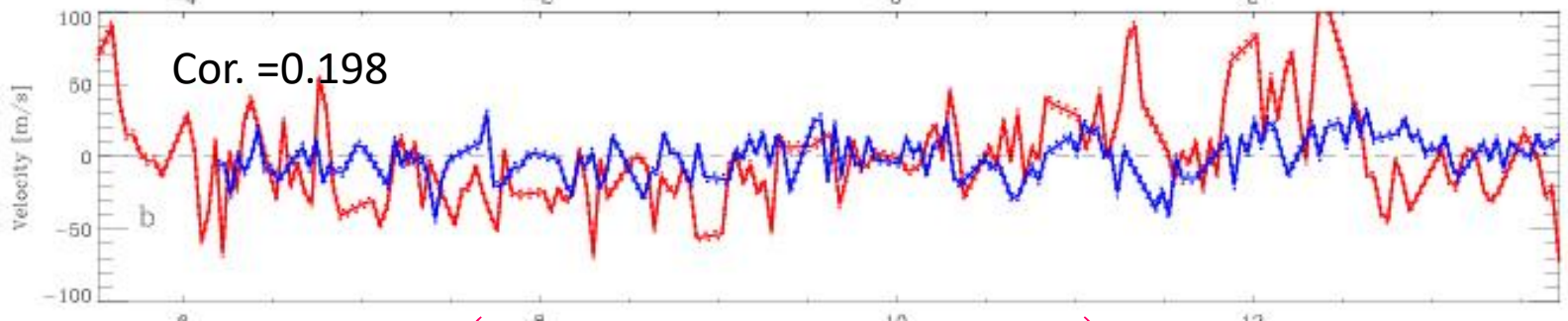
Fig. 5. Schematic model showing the location of the FPS at Poker Flat in relation to the auroral oval at the time of the upwelling. Arrows showing meridional and vertical winds are drawn to scale, and dashed lines mark the estimated size of the upwelling region.

Price et al., 1995

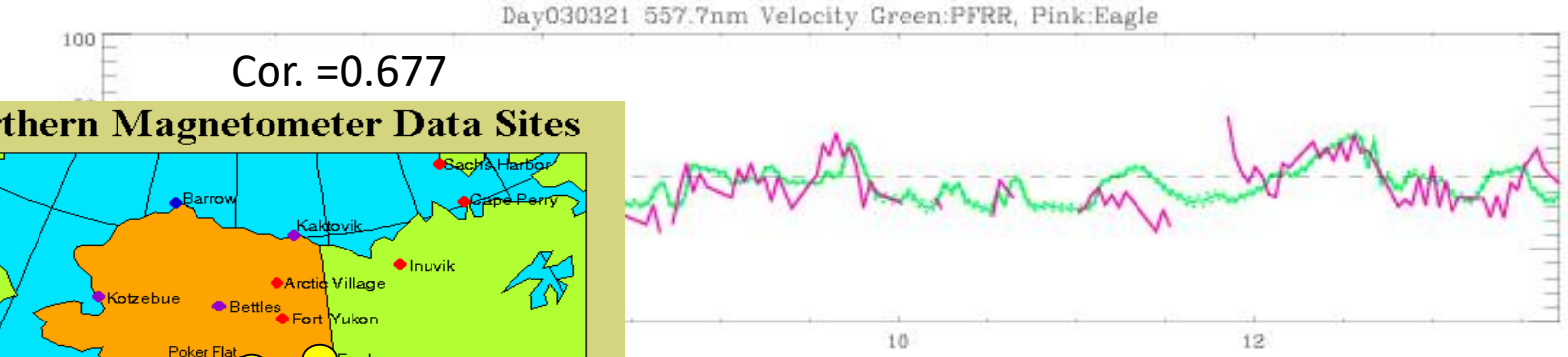
Measurement of vertical wind near aurora (Mar. 21, 2003)

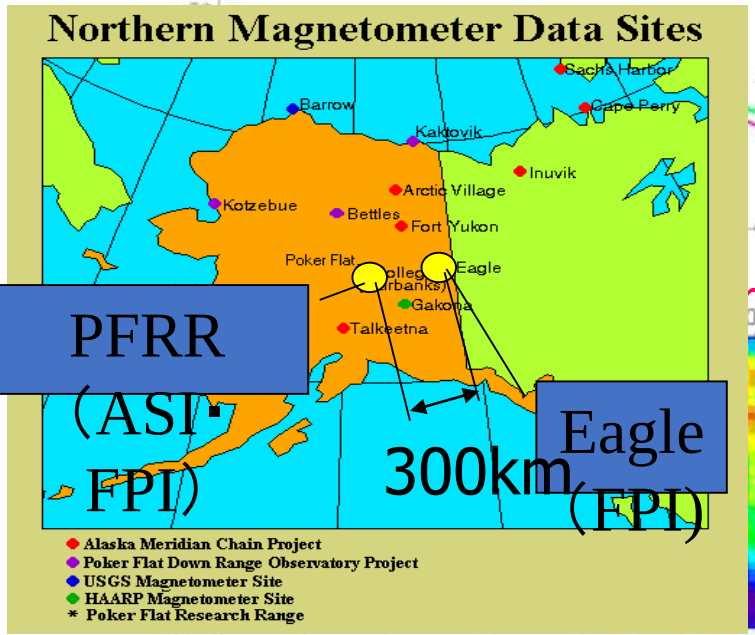
Ishii et al., 2004

630nm wind velocity （red：PFRR、Blue：Eagle） Estimated height:240km



557.7nm wind velocity （green：PFRR、 pink：Eagle） Estimated height: 110km



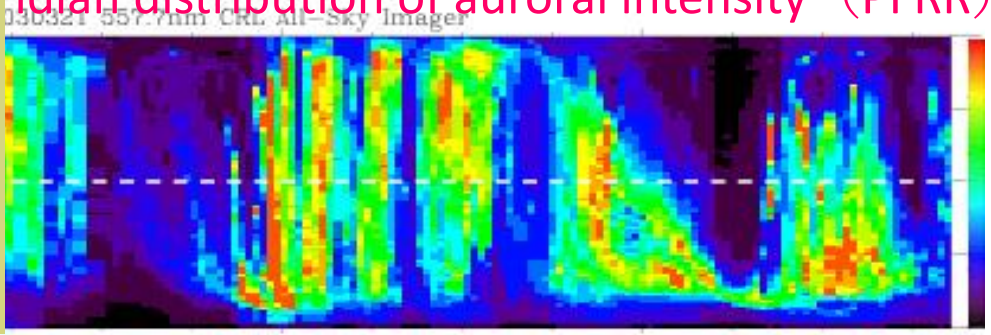


PFRR (ASI・FPI)

300km

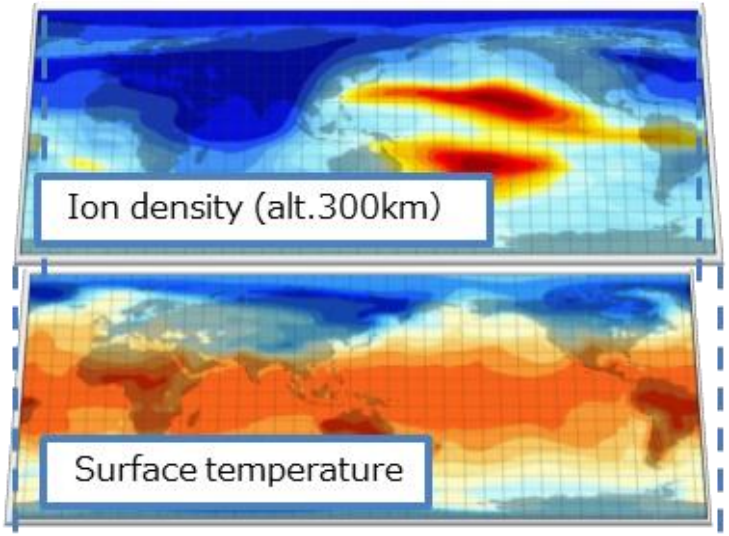
Eagle (FPI)

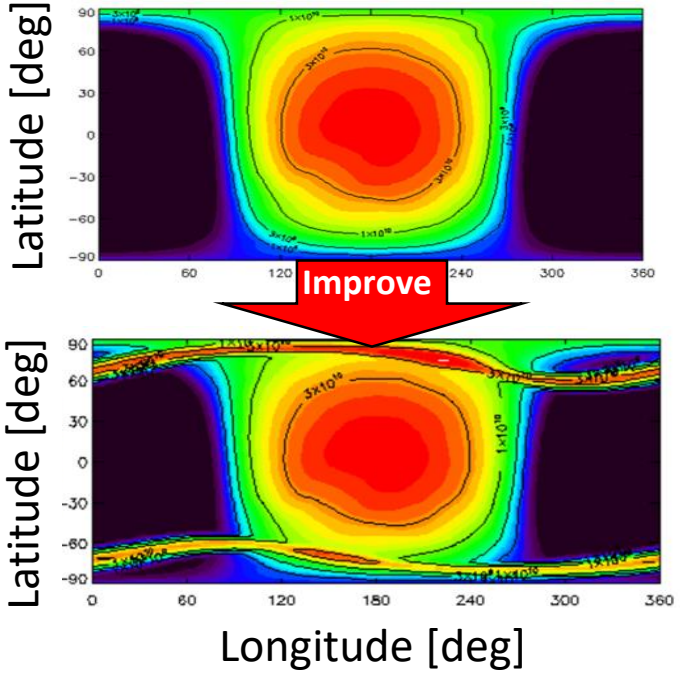
idian distribution of auroral intensity （PFRR）



Numerical atmospheric model

- NICT has been developing global atmospheric model named “GAIA”
  - It allows to calculate from the ground to the height of 500km with seamlessly.
  - It includes the effect of ground meteorology and solar activities (partially).
- NICT try to include auroral heating effect in “GAIA”
  - Hope to contribute to the quantitative estimation of air drag.





Conclusions

- In near future, the use of small satellites will increase exponentially.
- We need quantitative knowledge of air drag for small satellites. This information can be used for tracking of debris/near Earth orbital object and important on the view of SSA.
- There are two kinds of affects from air drag: breaking with air drag, and fluctuation of satellite attitude.
- It is relatively lower impact on the breaking effect: the estimated situation is very severe and will happen rarely.
- The fluctuation of satellite attitude is more serious shown in ASCA case. It may be occurred with complicated atmospheric condition by auroral heating which is still difficult to estimate.
- On the other hand, numerous trajectory data of small satellites will make us to receive information of air drag. It is important to keep these information accessible to improve numerical models.