PPS007-09

2010 JpGU Meeting, Makuhari, May 26, 2010

Optical lightning detection for investigation of atmospheric dynamics in Jupiter

木星大気ダイナミクス研究のための雷放電発光観測

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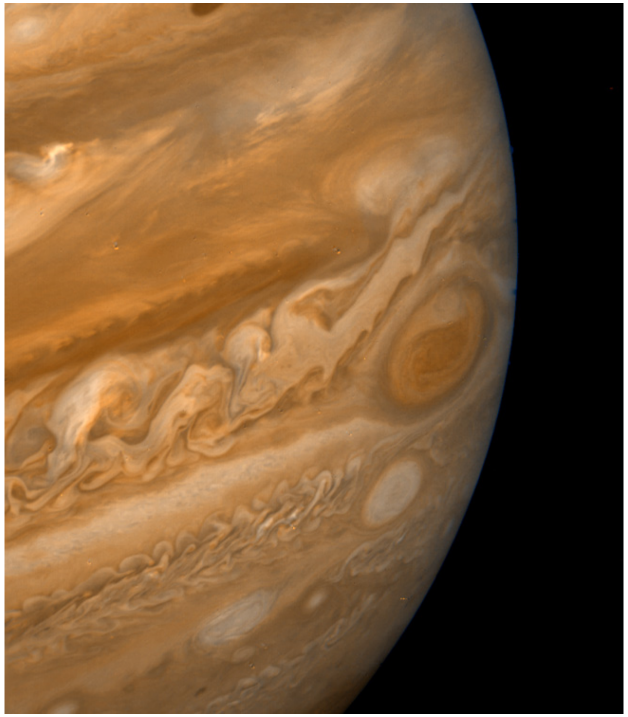
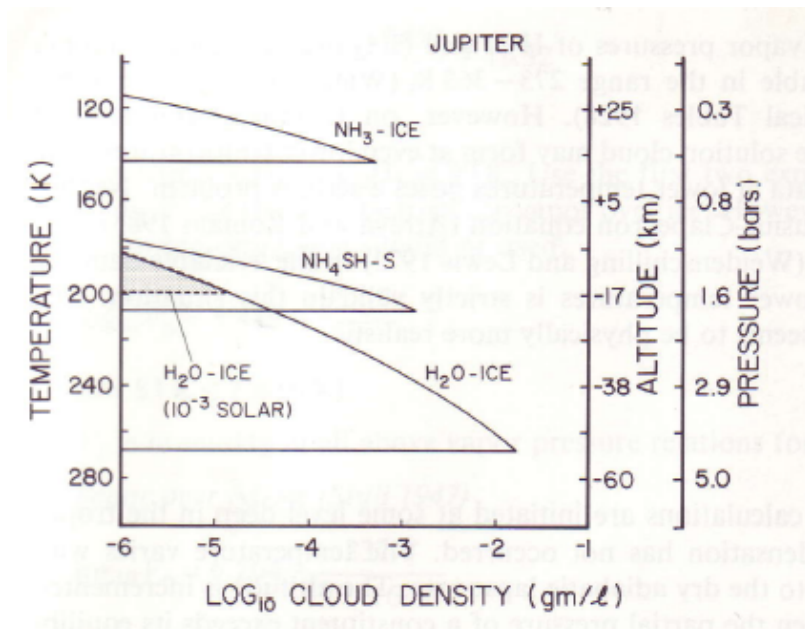
Jupiter's atmospheric structure

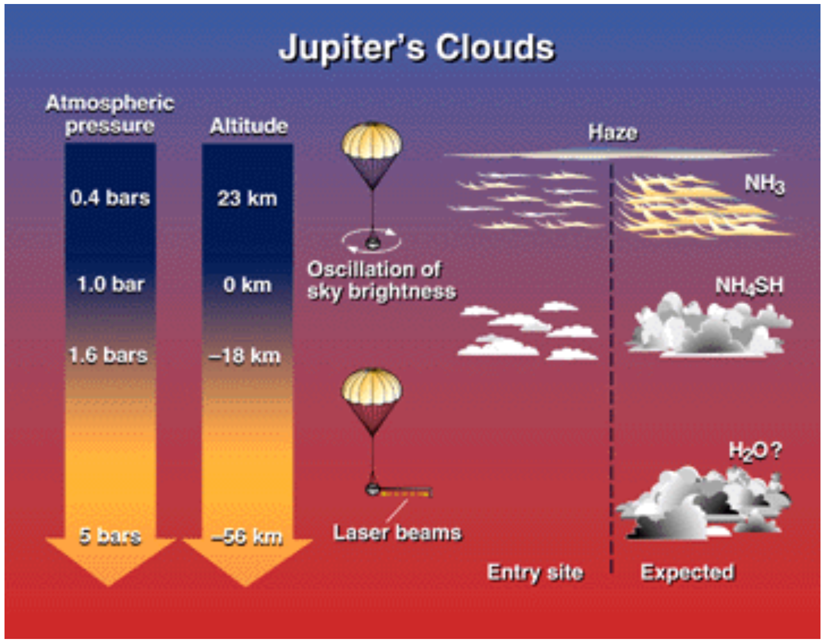
- Dark belts and bright zones circle the planet at constant latitudes, separated by zonal jets flowing at 180 m/s both eastward and westward.
- Large-scale ovals (~10,000 km) are typical weather systems lasting 10s of years, and display anti-cyclonic motion between the jets.
- Equatorial plumes are considered a marker for moist convection, as anvils of thunderclouds in the deep water cloud layer (Stoker, Icarus, 1985, 1986).



The Clouds of Jupiter

- Permanent global coverage organized in belts and zones
- Lower cloud - probably water - 5 bar pressure level, convective, mixed-phase
- Middle cloud - NH_4SH at the 2 bar pressure level, stratiform
- Upper cloud - Ammonia Ice, Cirrus-like





•**Lightning was predicted by Bar-Nun (1975) based on non-equilibrium chemistry.**
•**Comparable to terrestrial "Super-bolts"**
•**Mixed-phase water cloud seem to be the best candidate (Levin et al., Icarus, 1983).**

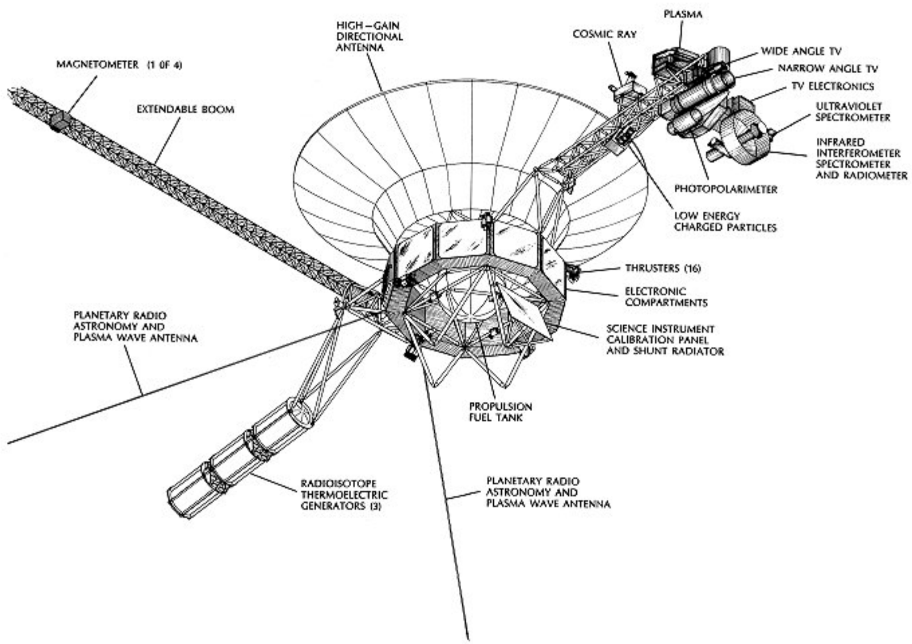
What are the possible contributions by Japanese team to atmospheric science in Jupiter?

- Thundercloud simulation

- Lightning detection by spacecraft

- Spectral imaging with telescope

First detection of Lightning – Voyager 1, 2



<u>Voyager 1</u>

- 20 luminous events [30N, 49N 55N]

(Cook et al., 1979, Smith et al., 1979)

- 167 whistler signals [source at 66N]

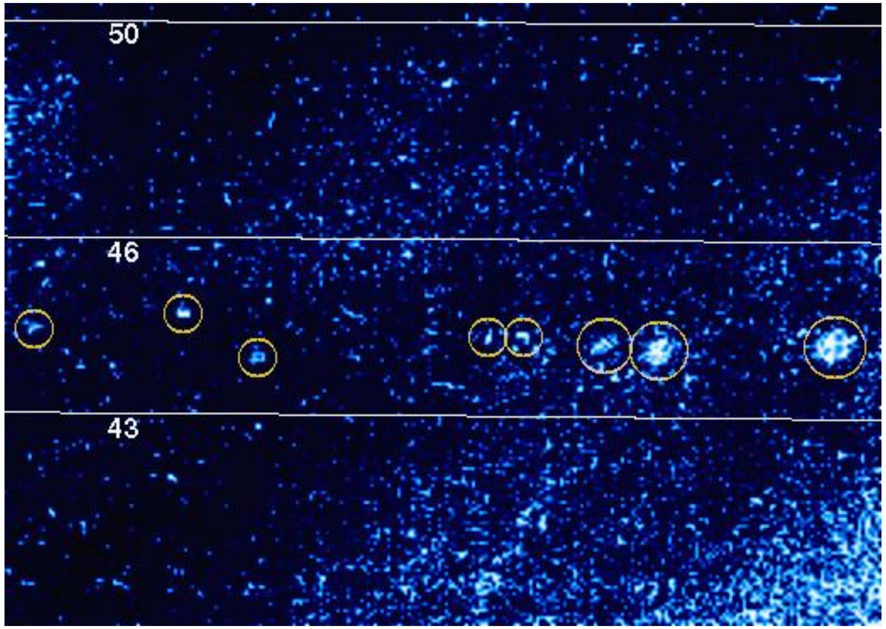
(Scarf et al., 1979, Gurnett et al., 1979)

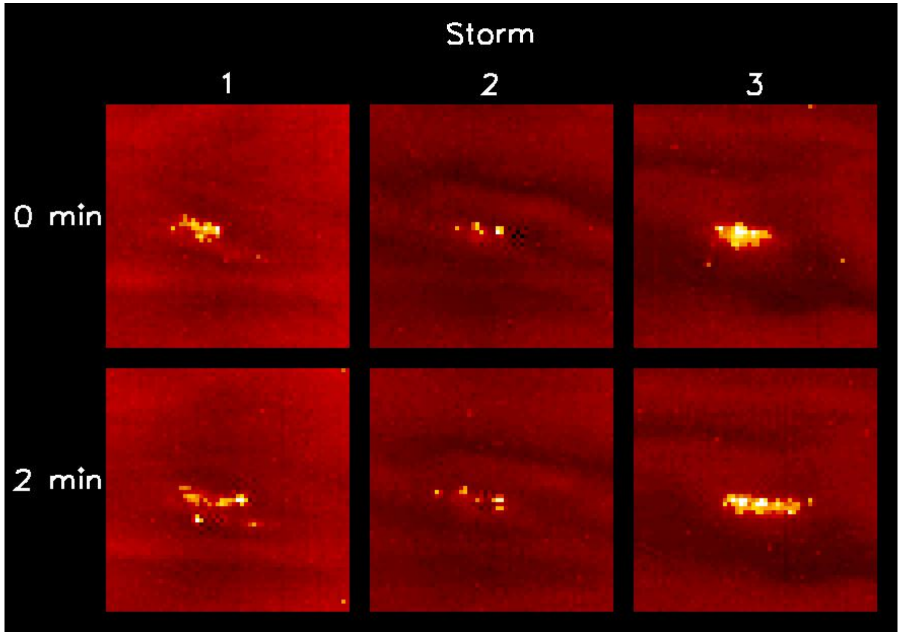
<u>Voyager 2</u>

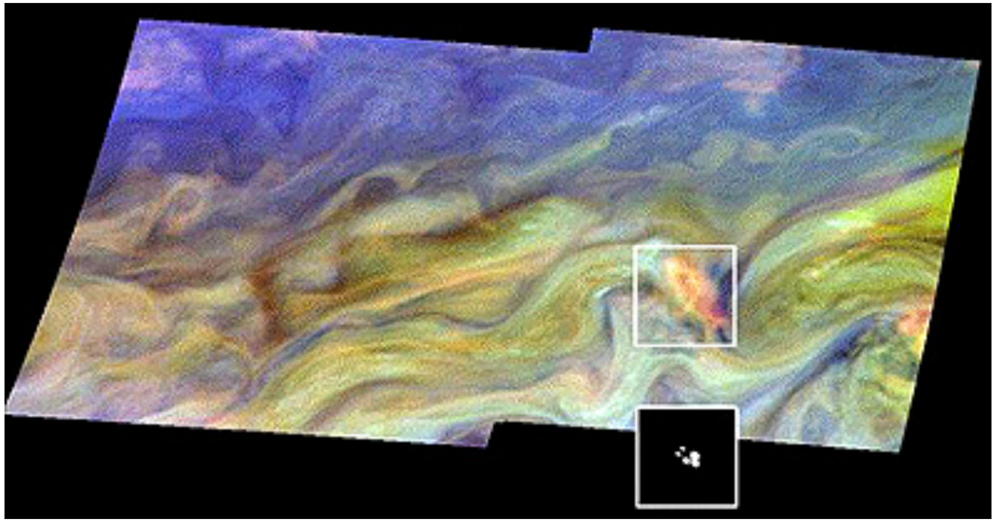
- 3 images with bright spots [13.5N, 49N. 60N]

(Magalhaes and Borucki, 1991, Borucki and Magalheas, 1992)

Optical Detection: Galileo, Cassini







Storms are long lasting and the flash rate is high, very bright and energetic.

Occur at mid- and high latitudes, less near the equator, especially in the belts

Lightning on Jupiter observed by the Cassini ISS 33

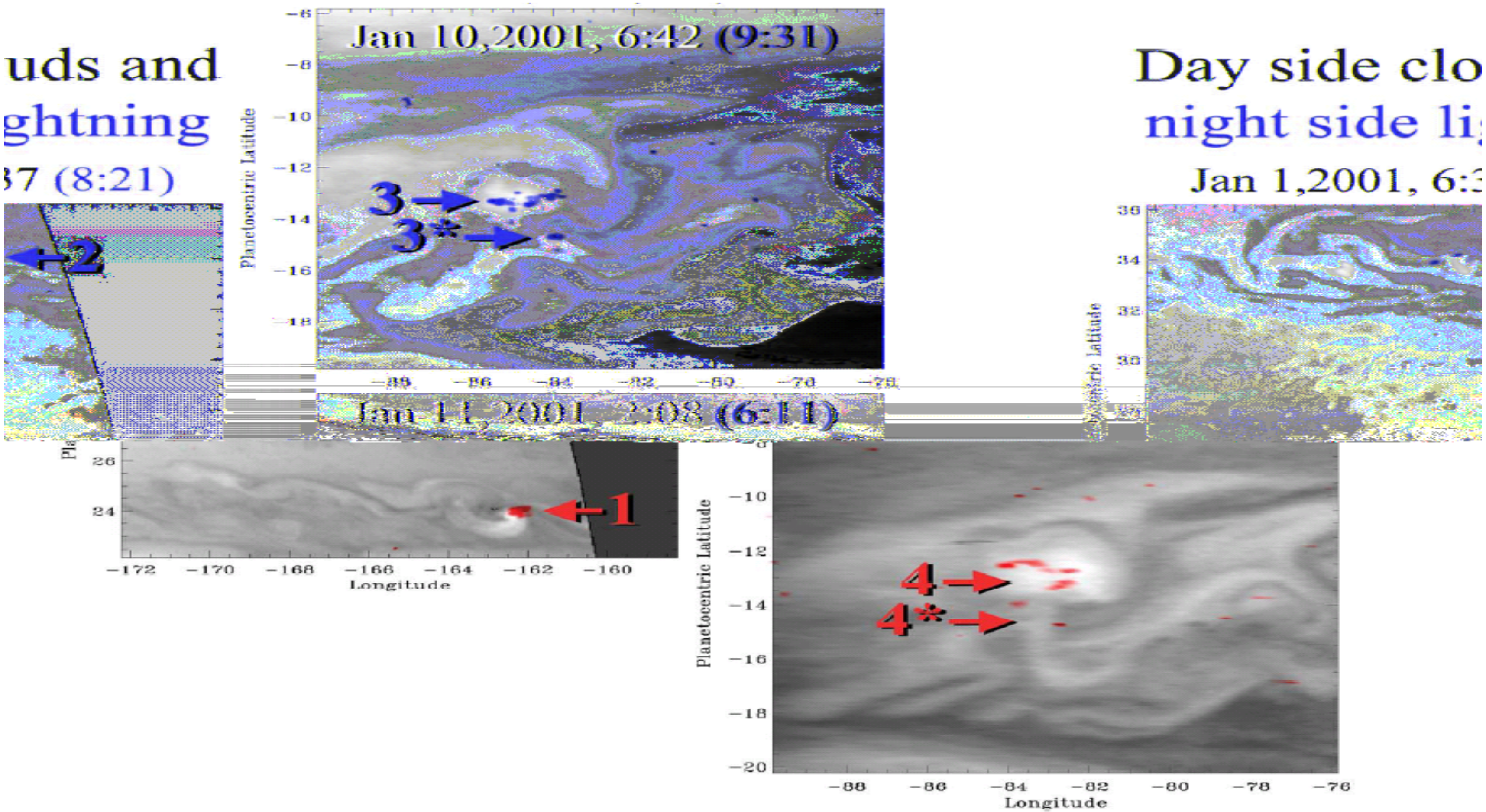
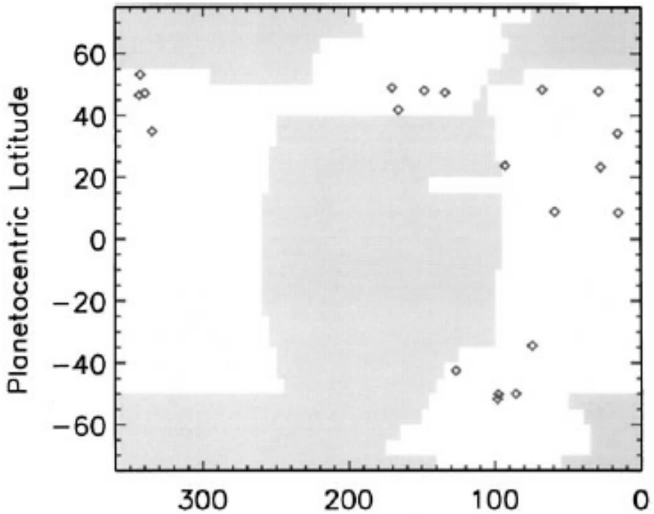


Fig. 8. Lightning on the night side of Jupiter (red) correlated with the clouds on the day side (greyscale) taken several hours earlier. Lightning spot numbers are labeled according to Table 2. The time is labeled on the images in red and black/white for the night side and the day side observations respectively. The image overlay and latitude/longitude scales are subject to a navigational error of less than 2°, one degree corresponding to about 1200 km. The red arrows point to the lightning spots listed in Table 2. The two images on the right display the same cloud in the turbulent wake of the Great Red Spot taken 2 jovian rotations apart.

Lightning is detected mainly in the belts, associated with optically thick, high white cloud clusters that appear suddenly and grow ~ days to diameters > 1,200 km.

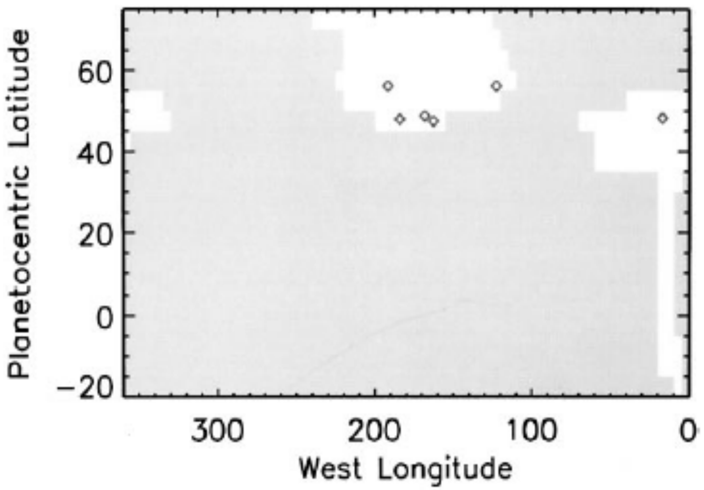
Relating cloud features to optical flashes in Galileo images
(Little et al., Icarus 142, 1999)

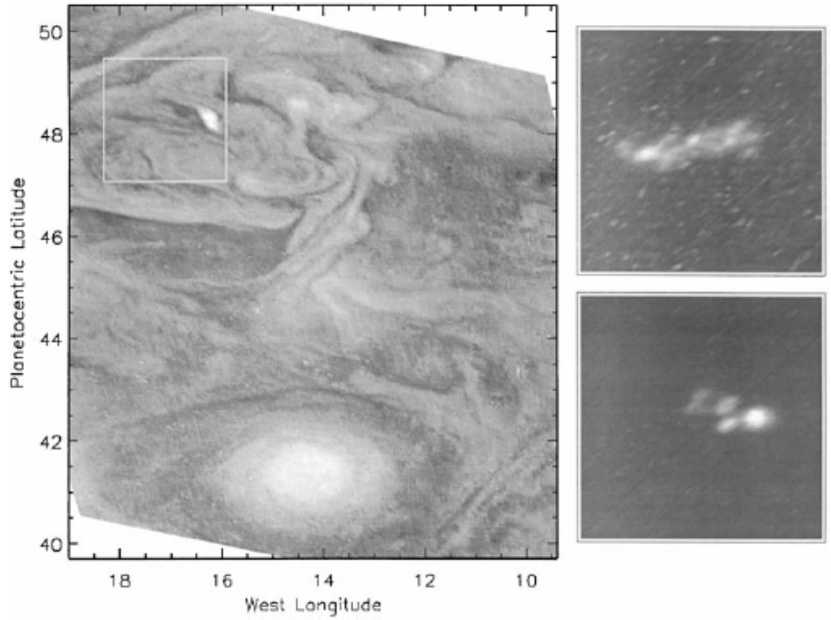


Latitude Distribution of Lightning Storms

Central latitude (deg)	Number of storms	Area (10^9 km^2)	Number/area (10^{-9} km^{-2})	Probability
57.5	2	1.02	1.96	
52.5	1	2.03	0.49	
47.5	11	2.62	4.19	5.0×10^{-6}
42.5	1	2.38	0.42	
32.5	2	1.47	1.36	
22.5	2	1.51	1.33	
7.5	2	1.58	1.27	
−32.5	1	1.34	0.74	
−42.5	1	1.40	0.71	
−52.5	3	0.45	6.68	0.251
Total	26	39.5[a]	0.66[a]	

[a] Total area surveyed, including bins that did not contain lightning.



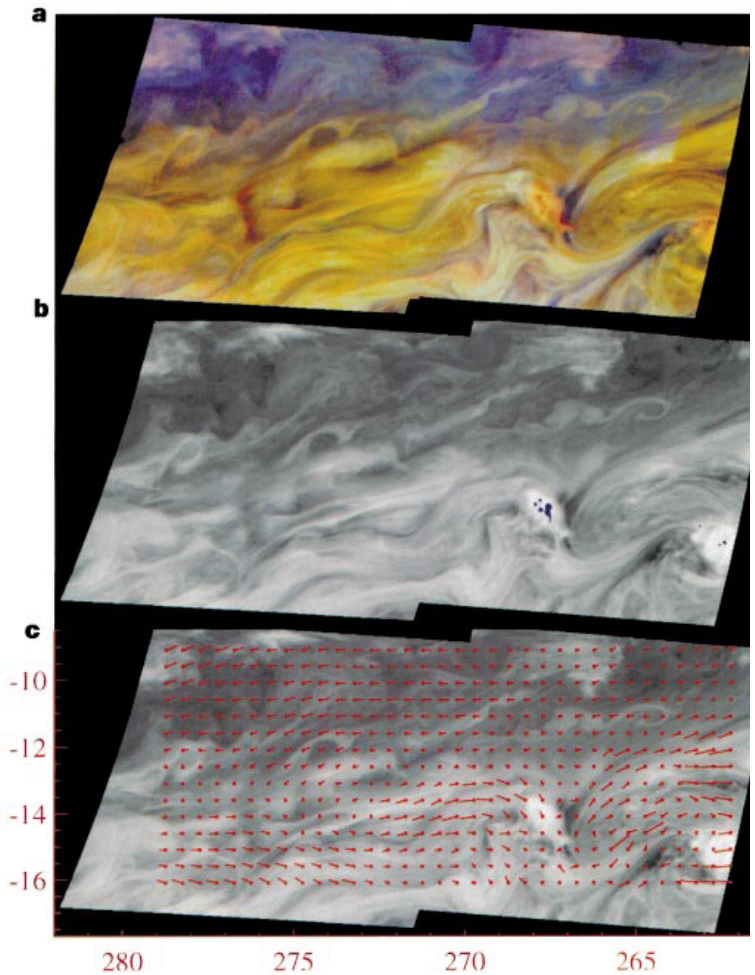


Moist convection as an energy source for the large-scale motions in Jupiter's atmosphere (Ingersoll et al., Nature, 2000)

- Small-scale eddies drive both the jets and the ovals, receive their energy from moist convection.
- The eddies are moist convective structures, and form a self-sustaining cycle: they maintain the jets and the interaction produces a pattern of upwelling and downwelling that helps maintain the eddies.
- Moist convection is driven by instability created by the deep heat flow, and the condensation of water vapor leads to clouds ~80 km deep which produce lightning
- The small eddies get their energy from the deep atmosphere and interior through moist convection

Observation of moist convection in Jupiter's atmosphere (Gierasch et al., Nature, 2000)

- The total vertical transport of heat by storms is of the same order as the planet's internal heat source.
- Moist convection - similar to large clusters of thunderstorm cells in the ITCZ on Earth – may be a dominant factor in converting heat flow into kinetic energy in the Jupiter's atmosphere



Mapped images of the storm region. There are two storm centres, near latitude 14 S, longitude 268 W and latitude 15 S, longitude 263 W, respectively

Sugiyama et al., 2009, 2010

Numerical modeling of cloud convection -- the model and the set-up --

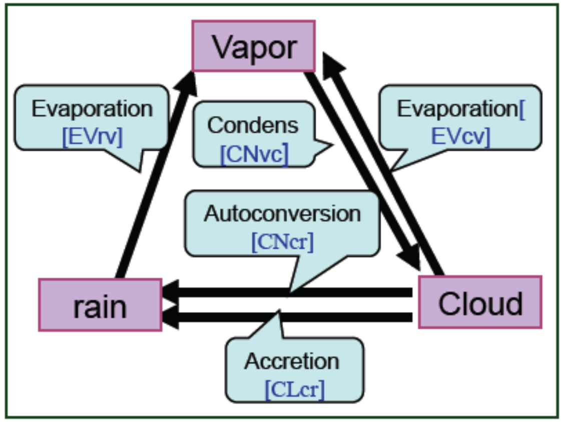


Fig.A: Schematic figure of cloud microphysics parameterization.

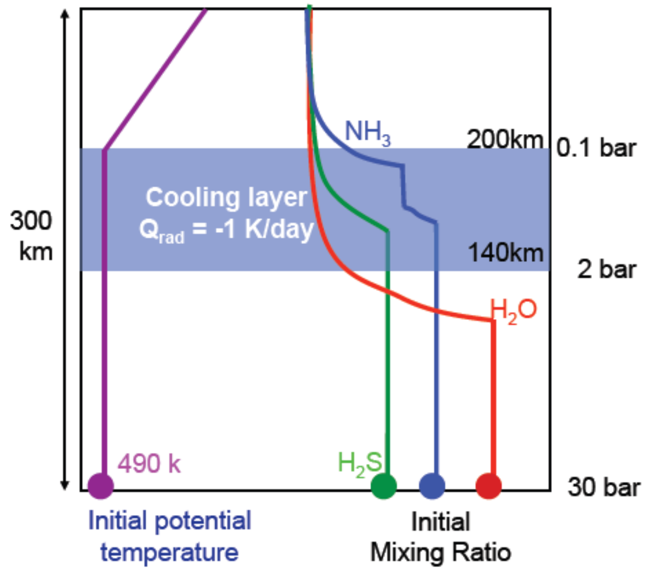
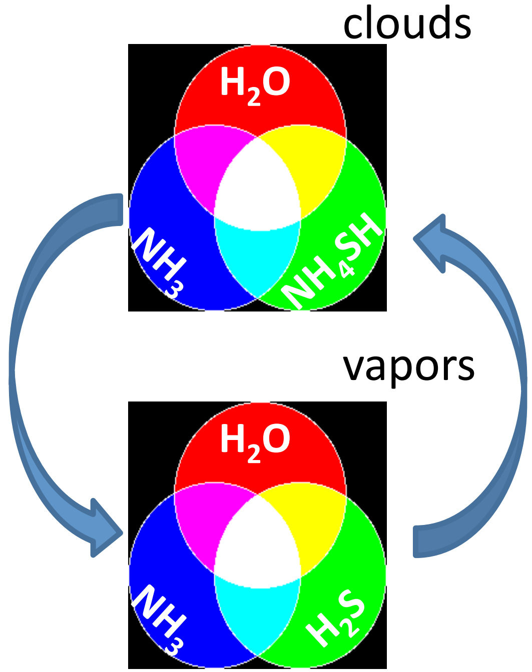


Fig.B: Schematic figure of model settings.



Basic equations (2-Dimensional Model)

- The basic equations of the model are based on the quasi-compressible system (Klemp and Wilhelmson, 1978) and conservation equations of condensible species.
- The cloud microphysics are implemented by the parameterization schemes of Kessler (1969) (see Fig.A).
  - The conversion rate due to accretion (CLcr) and fall velocity of rain is specified as three times the value used in terrestrial case considering strong gravity and small air density in Jupiter's condition (Cf. Yair *et al.*, 1995).
  - The time constant of autoconversion of the rain water (CNcr) is 100 sec and its critical "cloud" mixing ratio is 0, following Nakajima *et al.*(2000).
- The effect of subgrid turbulence are implemented by the parameterization schemes of Klemp and Wilhelmson (1978) .

Set-up of Experiments (see Fig.B)

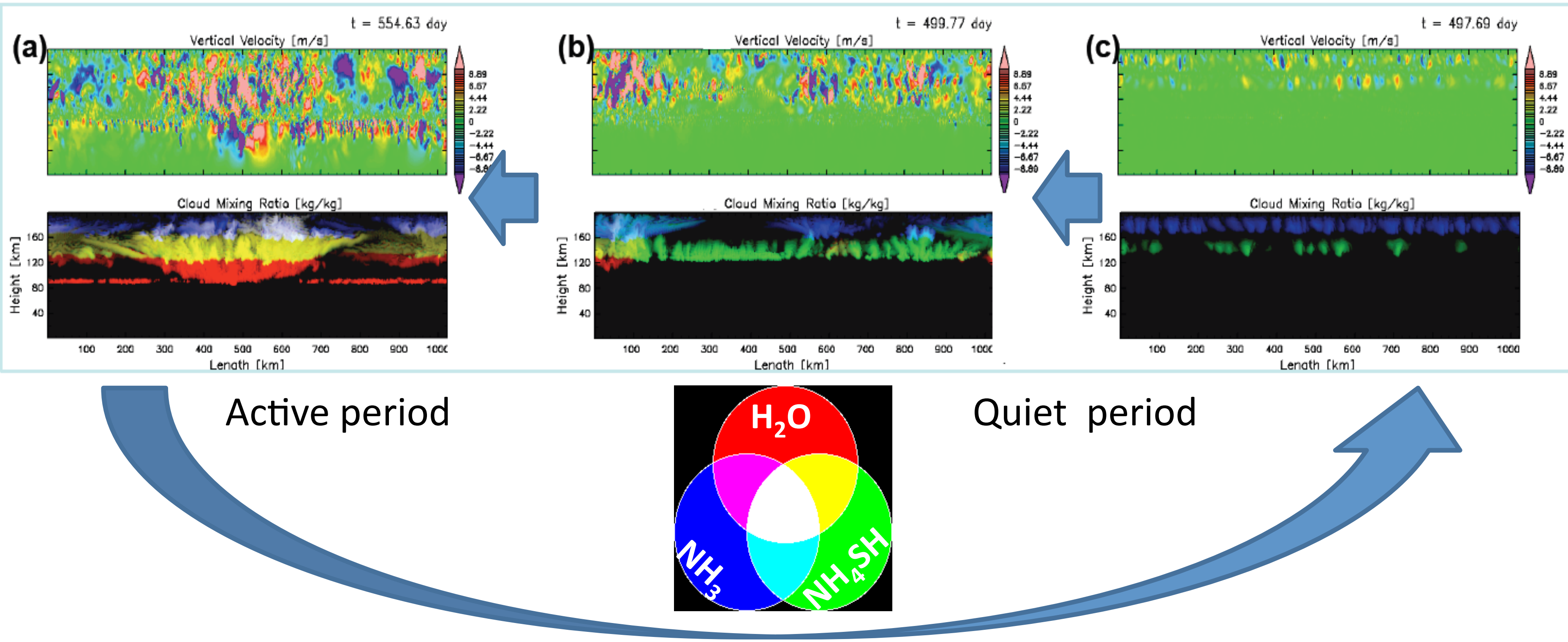
- The computational domain extends to 1024 km horizontally and 300 km vertically. The grid interval is 2.0 km.
- The atmosphere is cooled (Q_{rad}) between 140 km (2 bar) and 200 km (0.1 bar) at a constant rate of -0.1 K/day.
- Boundary conditions
  - Horizontal boundary is cyclic. Stress free condition and w = 0 are given at the lower and upper boundaries.
  - Temperature and mixing ratios of vapor at the lowest level are fixed.
- Initial condition
  - The isentropic atmosphere (**T=160K at p=0.6bar**) is assumed from 30 to 0.1 bar , and isothermal above 0.1 bar (100 K).
  - Deep abundances of vapor (H_2O, NH_3, and H_2S) are set to be 0.3, 1, 3, and 10 × solar taken from Asploud *et al.* (2005). Mixing ratios are reduced in the "cloud" layers so that the relative humidities do not exceed 75%.
  - Random potential temperature perturbation ($\Delta\theta_{max}$ = 0.1 K) is given to seed convective motion.

Sugiyama et al (2009) Nagare Multimedia (On-line Journal of Japan Soc. of Fluid Mechanics)
Sugiyama et al (2010, to be submitted to ICARUS)

Sugiyama et al., 2009, 2010

Characteristics of simulated cloud convection

In spite that the thermal forcing driving the convection is kept constant, the simulated cloud convection is far from being steady. Both the intensity of convective motion and the structure of clouds exhibits distinct quasi-periodic cycle.



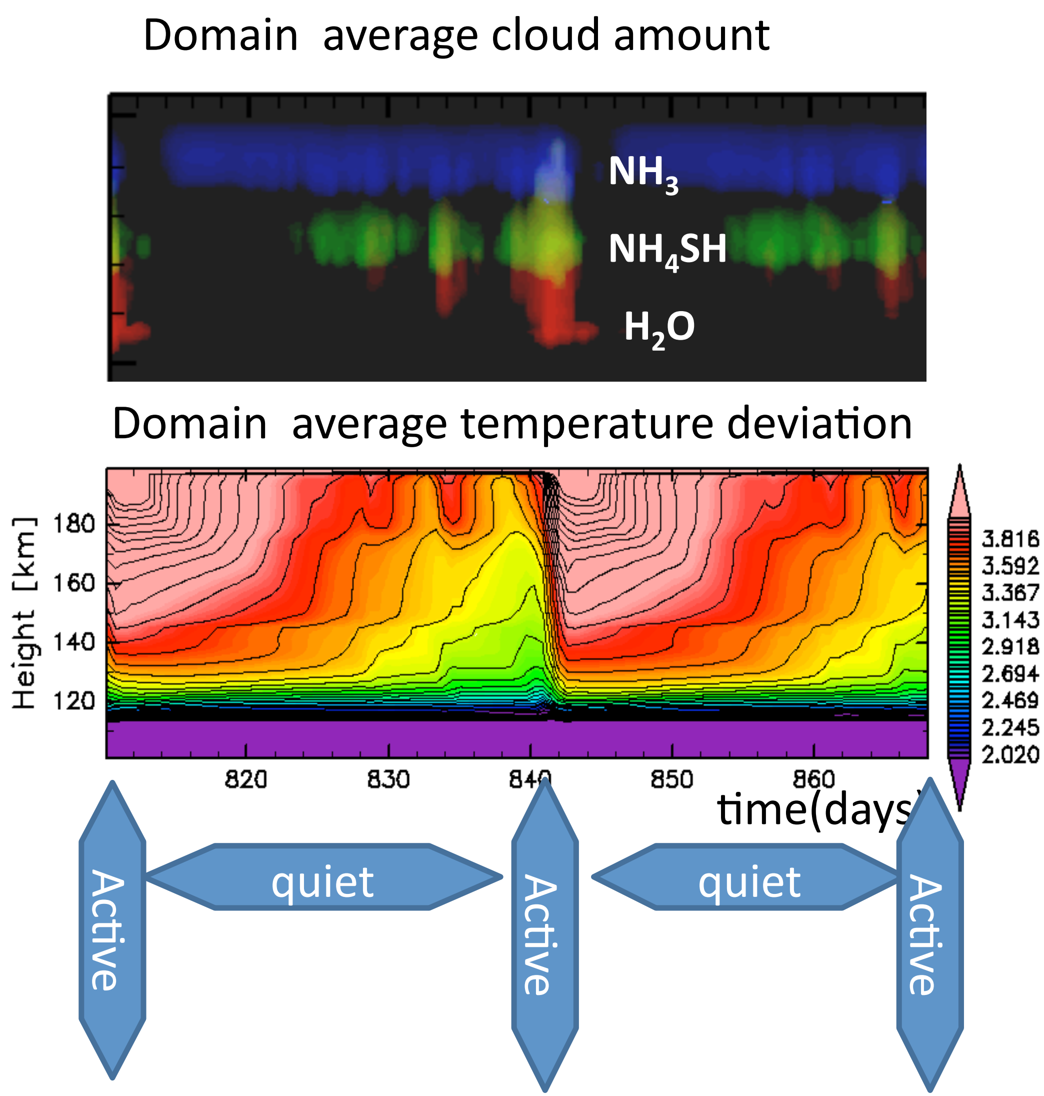
Sugiyama et al., 2009, 2010

Why is the cloud activity intermittent?

Associated with the strong water cloud convection in the "active period", the tropospheric temperature rises sharply.
The atmosphere becomes stable, and the cloud activity dies out, going to the "quiet period".

During the "quiet period", the atmosphere cools slowly by the "radiative" cooling.

When the atmosphere is cooled enough to be "convectively unstable", the water cloud convection returns, i.e., a new "active period".



Sugiyama et al., 2009, 2010

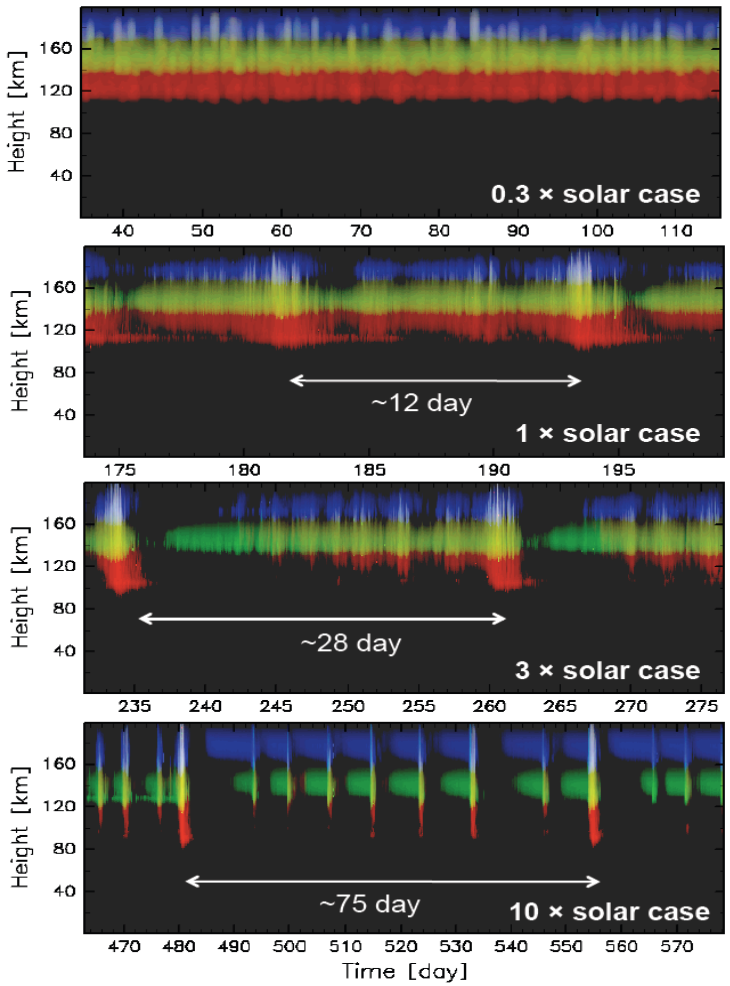
The time interval between active periods is roughly proportional to deep water vapor mixing ratio. Why?

The amount of temperature rise is roughly proportional to the deep water vapor mixing ratio.

The period, which is the temperature rise divided by the cooling rate, also become proportional to deep water content.
Present experiments show such tendency.

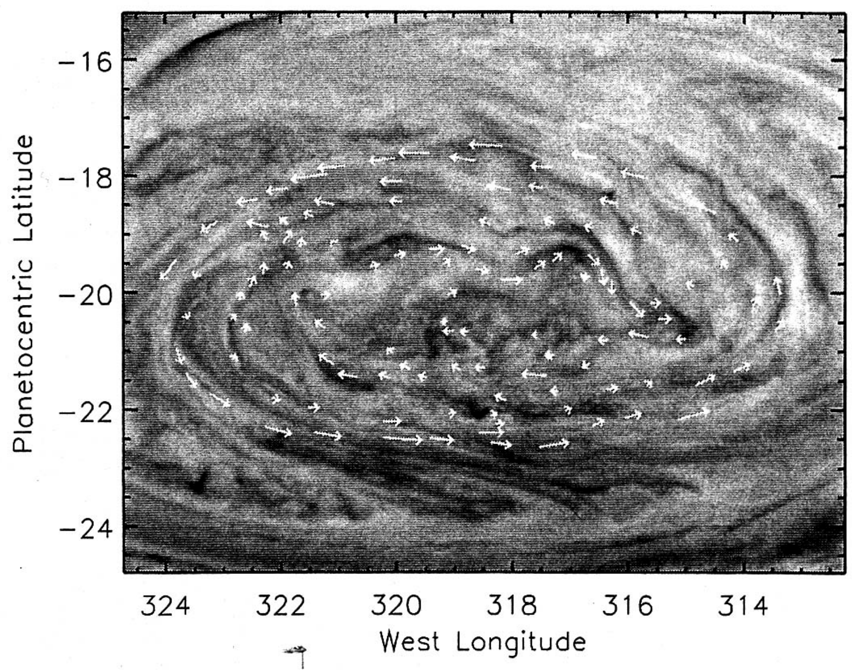
The periodicity of clouds gives us hints on deep water vapor content.

N.B. Present experiment is done with the cooling much stronger than in real Jupiter's atmosphere.
With realistic strength of forcing,
the periods should be O(100-1000 days).



Cloud tracking by orbiter

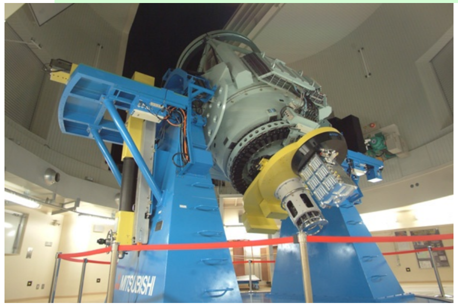
Simultaneous measurements of atmosphere such as spectral imaging, which determine the horizontal motion of clouds and the altitude of cloud top, are essential to investigate the role of thunderstorm.



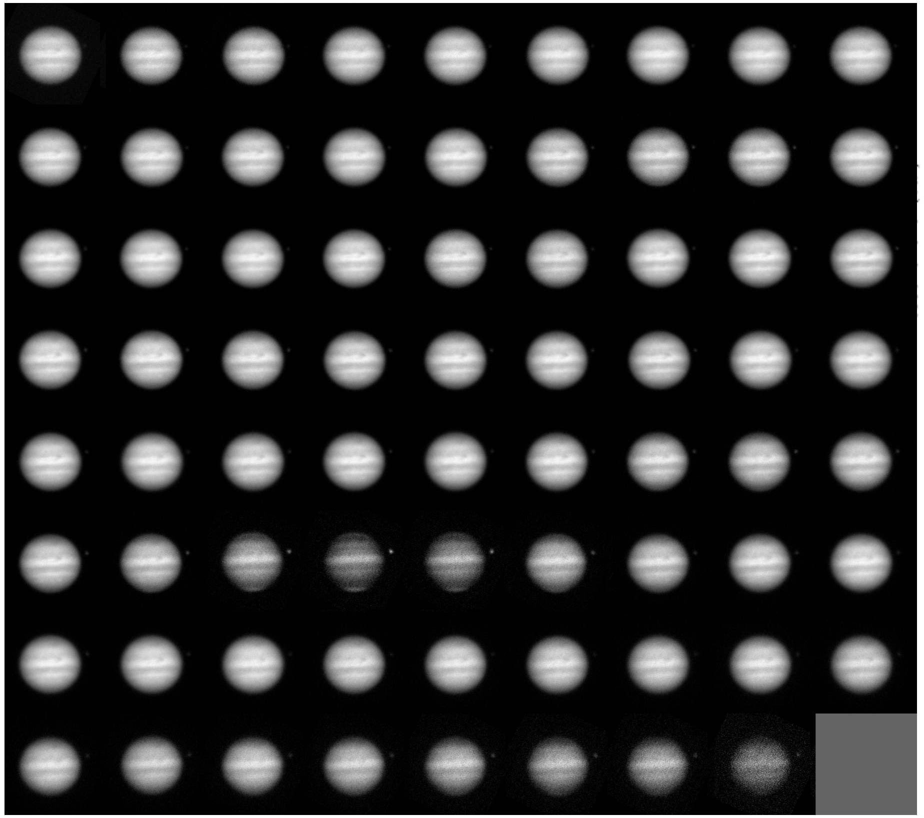
Cloud tracking provides information of wind speed and nature of eddies.

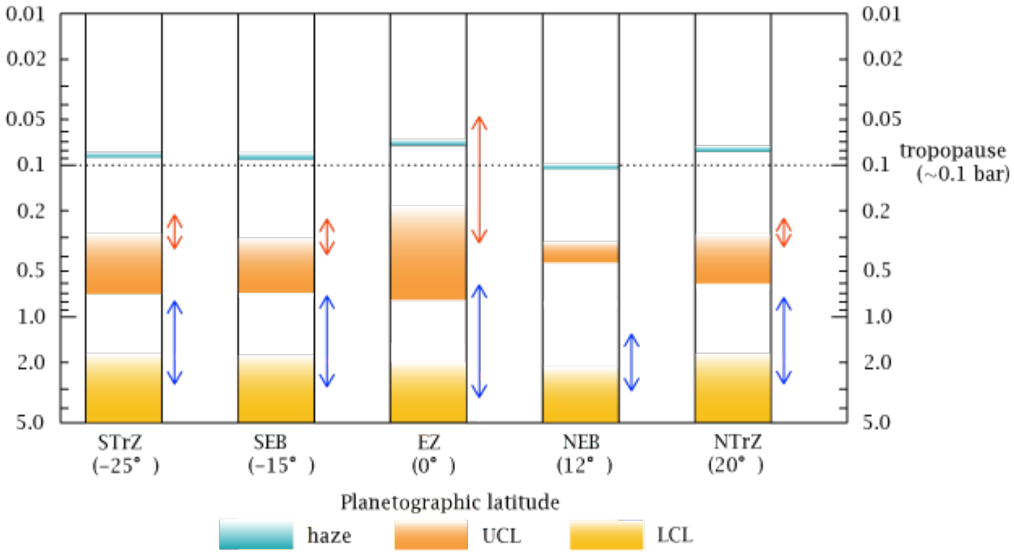
Spectral imaging by ground-based and spacecraft

Recent spectral imaging on the ground suggests no significant alt. difference of cloud top between NEB/SEB and NTrZ/STrZ (Sato, et al.)

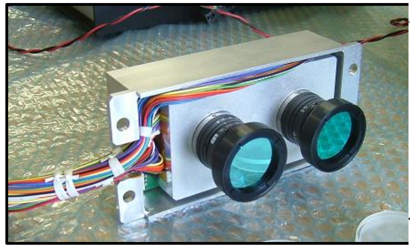


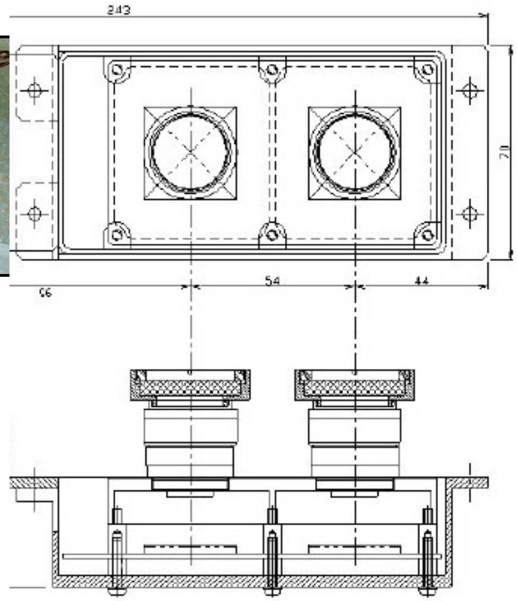
Multi-color imaging with Ground-based telescope and LCTF





Suggested instrumentation for lightning flash detection by orbiter



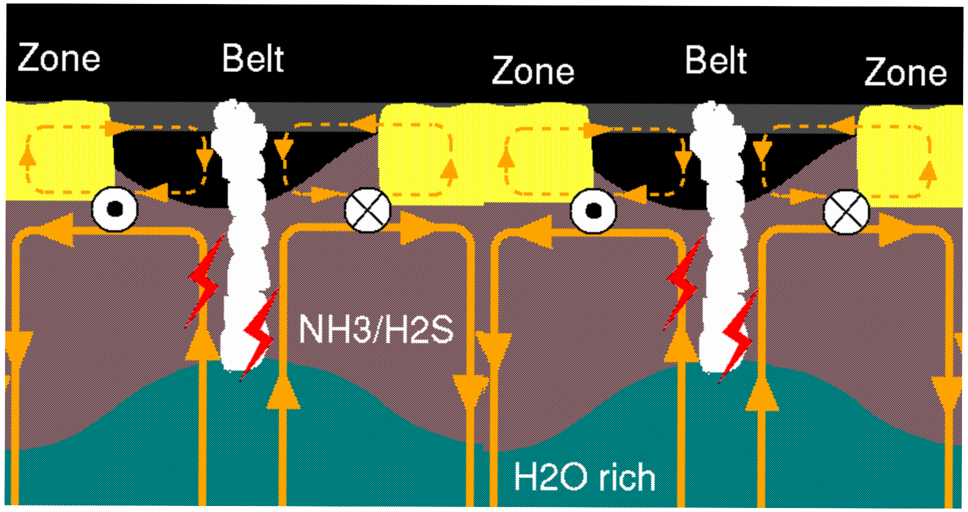


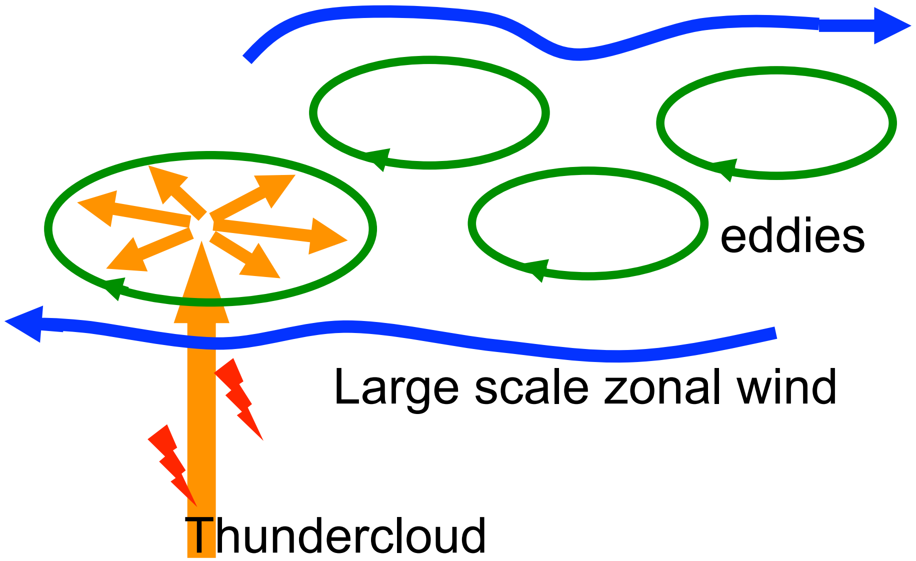
Sensor: CMOS (e.g., STAR250.. up to 10s of MRad)
Filter: H Balmer Alpha line (656.3nm) narrow/wide
Triggering: transient flash detected by FPGA logic
should be optimize for Jovian lightning
Sampling rate:
normal mode: 29ms for full frame (512x512 pixels)
high-speed mode: up to ~0.1ms
for 30x30 pixels by focusing thunderstorm area.
Weight: ~1kg
Size: 16x7x5.5 cm (sensor) and 16x12x4 cm (circuit case)
Power consumption: ~4W
Data: only intensity and pixel location with time …reduced significantly
Those specs. can be modified according to spacecraft resources,
or even can be combined with other imagers.

Strategy of thunderstorm study in Jupiter

to validate a possible scenario of momentum transfer by thundercloud, which make large scale structures

upward wind in thundercloud ➡ small eddies ➡ belt/zone and ovals

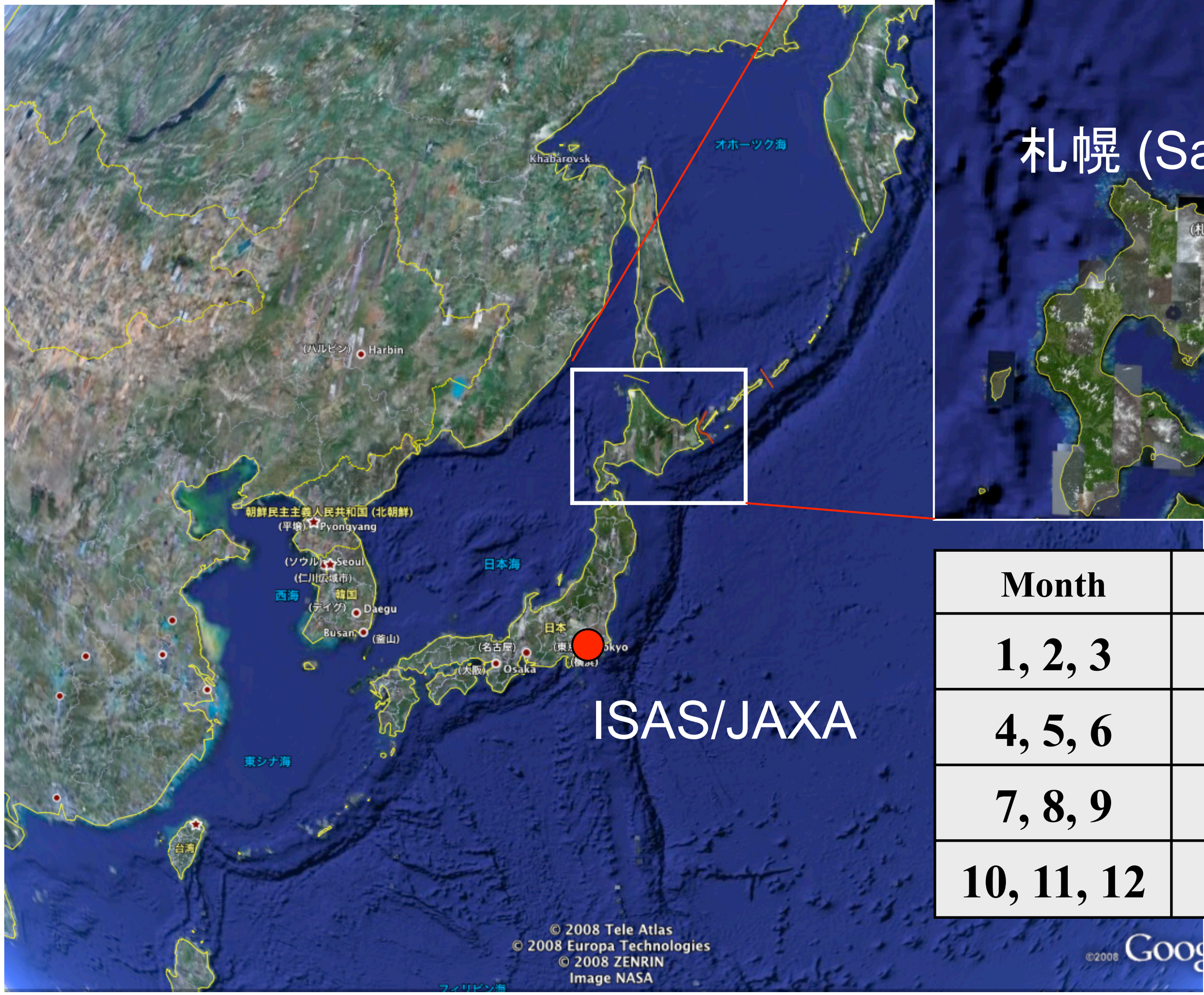




EJSM? (JGO, JEO, JMO)

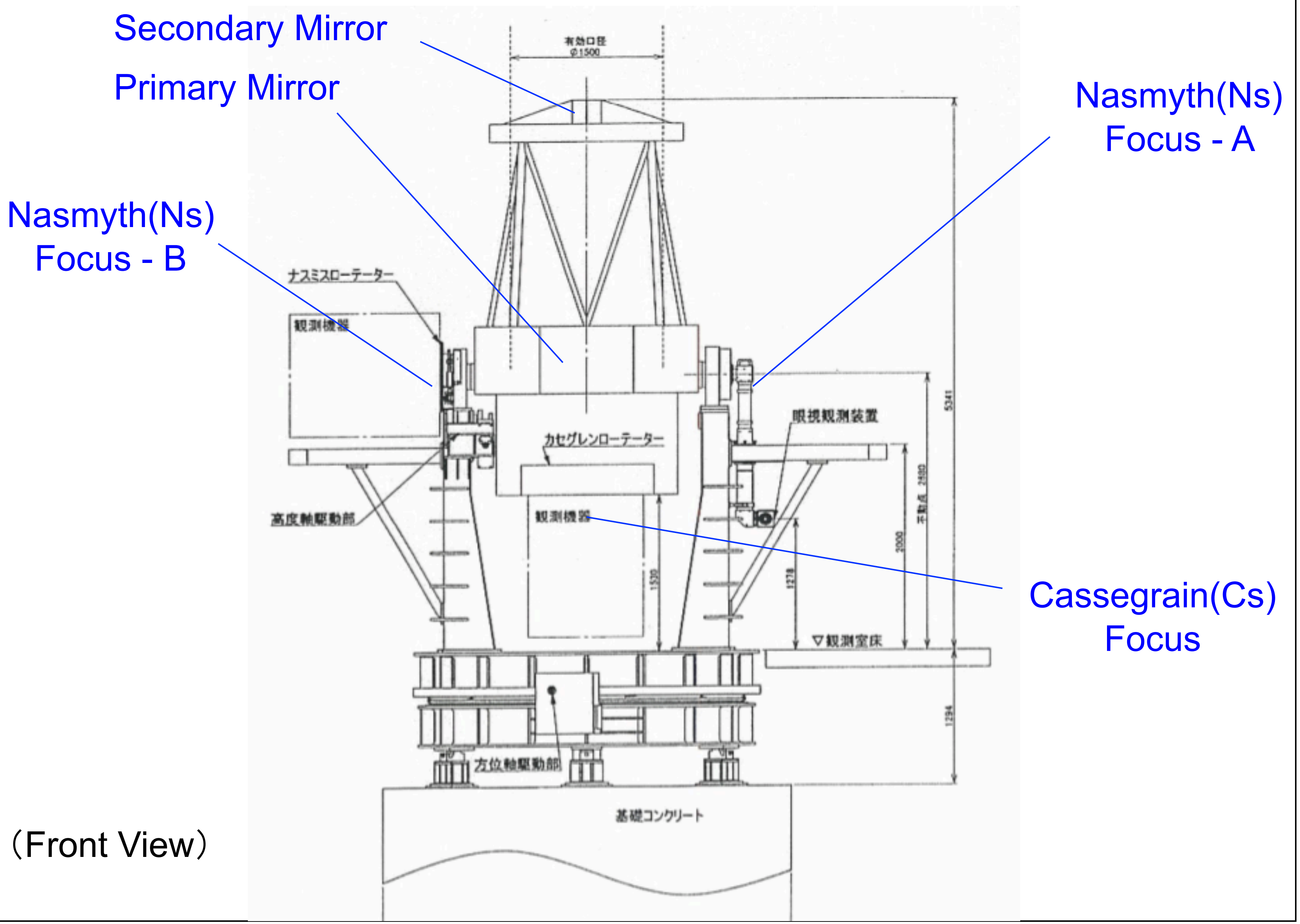
- **Wind velocity** in belt/zone, ovals and eddies… by cloud tracking
- **Cloud top altitudes** of belt/zone and thundercloud … by spectral imaging
- **Lightning activity with depth info.** … by lightning flash detector

Ground-based telescope for planetary obs. at Nayoro, Hokkaido, JAPAN



Month	Ave. Temp. (°C)	Precipitation (mm)
1, 2, 3	-7.8	50.0
4, 5, 6	+9.6	53.7
7, 8, 9	+17.9	117.4
10, 11, 12	+1.2	103.9

Main Structure of Telescope



（Front View）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Summary

Quantitative understanding of thunderstorm activity with cloud monitoring would be a key to solving mechanisms of zone/belt and big oval structures. It is also dedicated to probing of the water vapor in deep atmosphere.
Counting lightning flashes is the only effective an easy way to estimate thunderstorm activity quantitatively.

Japan has good experiences in thundercloud simulation, lightning detection, spectral imaging (and analysis).

Compact, light and simple detector onboard EJSM orbiters can be modified according to the spacecraft resources.

Ground-based telescope also may contribute to atmospheric science in Jupiter.