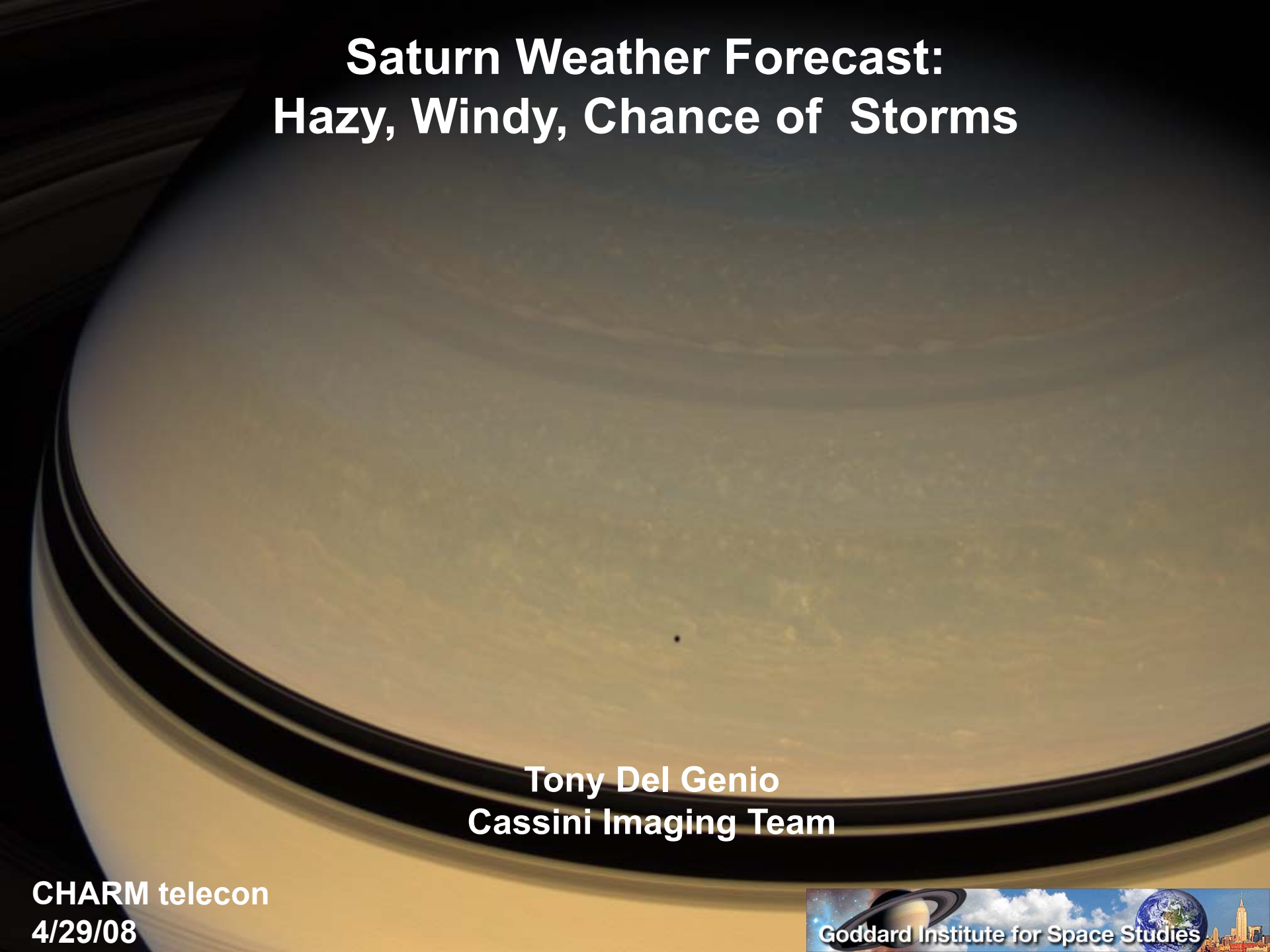
Saturn Weather Forecast: Hazy, Windy, Chance of Storms



Tony Del Genio
Cassini Imaging Team

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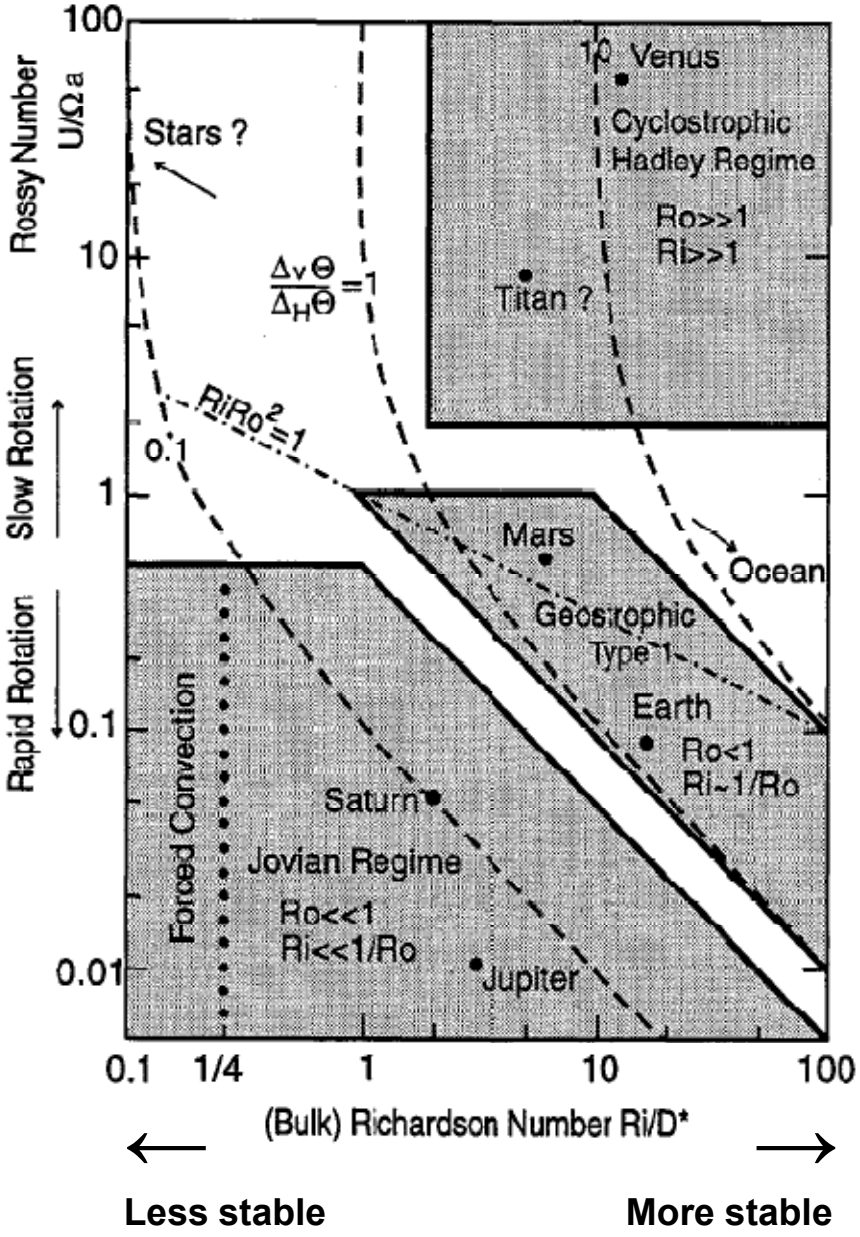
Motivations for studying the dynamics of Saturn's atmosphere

- Comparative planetology
  - Classification of Saturn among the planets
  - Saturn-Jupiter similarities and differences
  - Does our knowledge of Earth inform our study of Saturn?
- Global issues
  - Why is there banded cloud structure?
  - What maintains the alternating eastward and westward jets?
- Regional topics of interest
  - Evolution of equatorial jet
  - South polar vortex



Weather exists primarily to move heat from places of excess to places of deficit

Slowly rotating planets (Venus, Titan): poleward

Terrestrial planets (Earth, Mars): poleward + upward

Jovian planets (Jupiter, Saturn, Neptune): upward

Upward heat flux on Saturn reflects need for internal heat to get out

Earth: An observer's dream

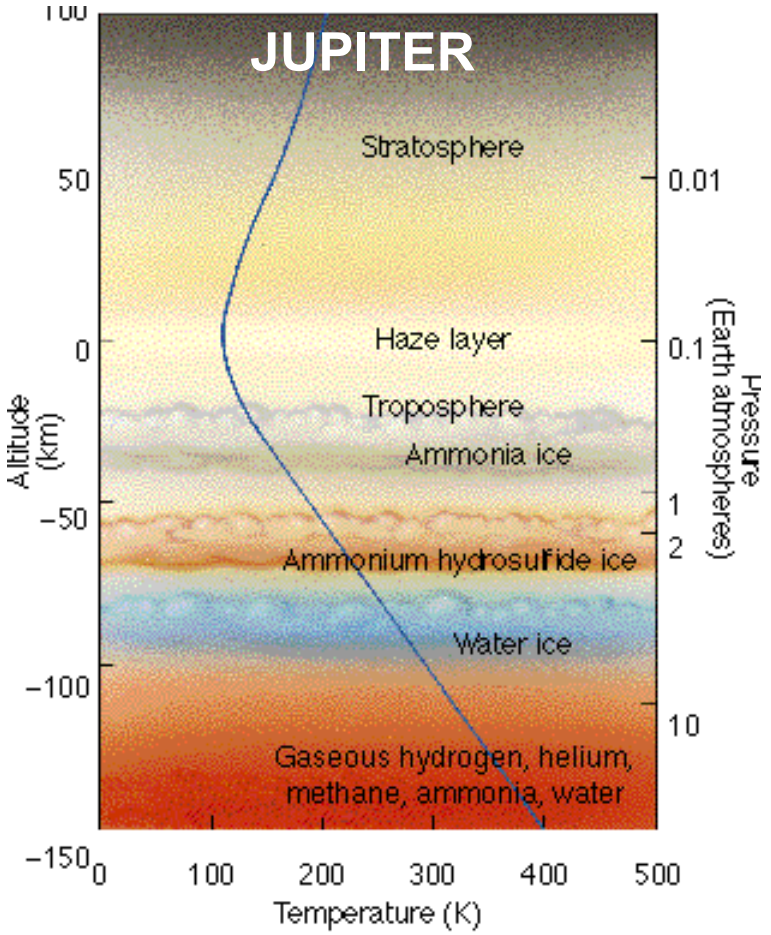
- Partly clear, partly cloudy; can see top to bottom
- Small – global observing easy
- No rings to get in the way!
- Strongly forced – phenomena of interest happen often
- People who launch weather balloons for "ground truth"

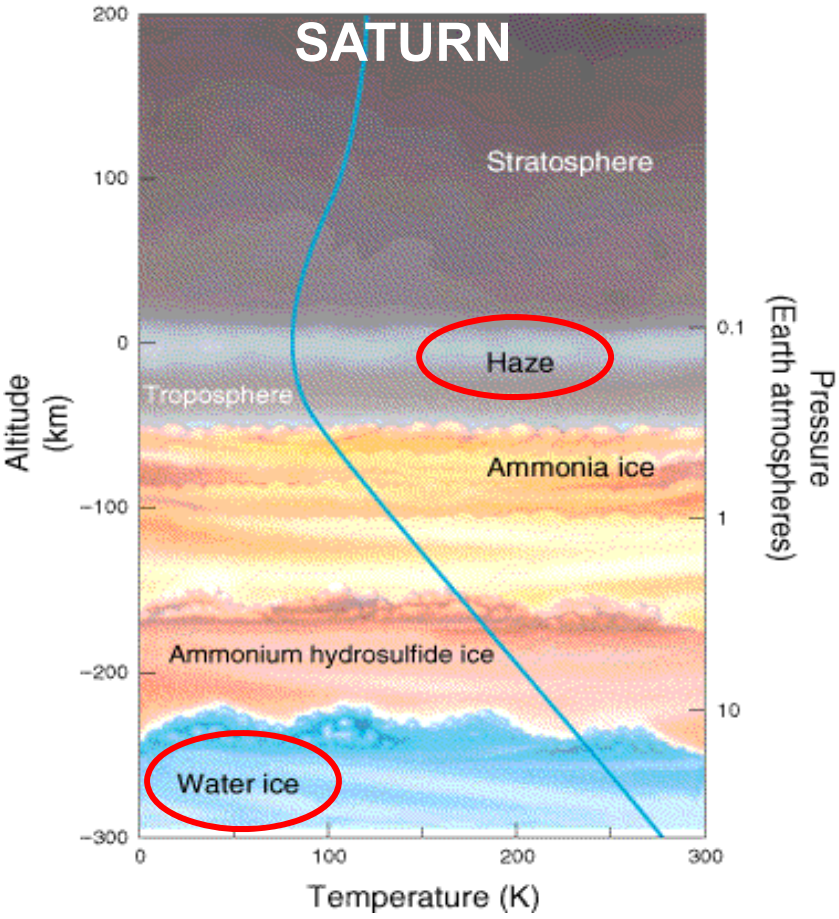
Saturn: An observer's nightmare

- Overcast; can't see below the clouds where action is
- Big – need to stay far away to see it all
- Lots of rings obscure the view
- Weakly forced – relevant processes occur once in a while
- Saturnians haven't yet released their weather data to NASA

Water clouds buried beneath ammonia and ammonium hydrosulfide clouds, deeper on Saturn than on Jupiter

Tropospheric haze thicker on Saturn than on Jupiter

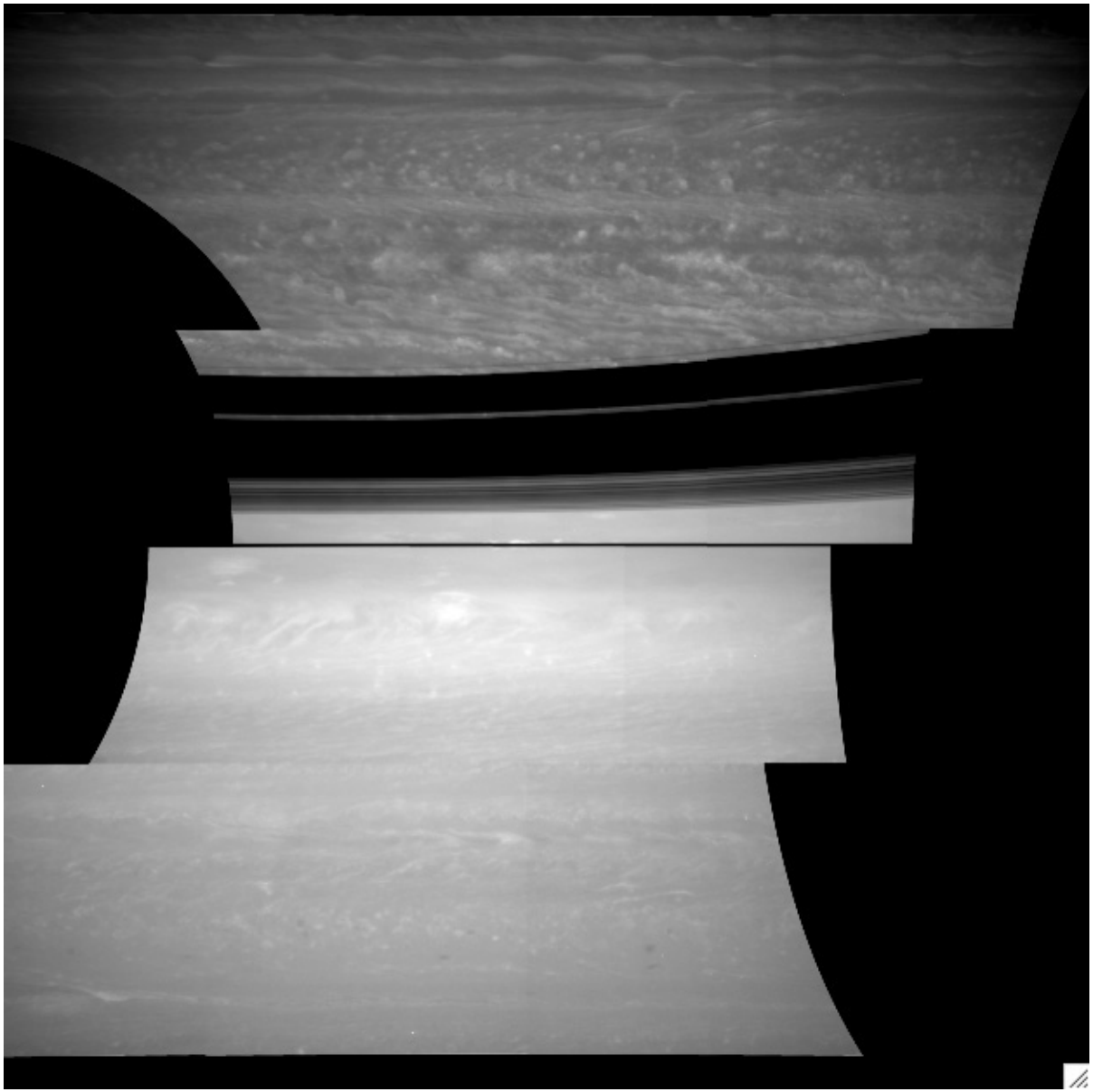




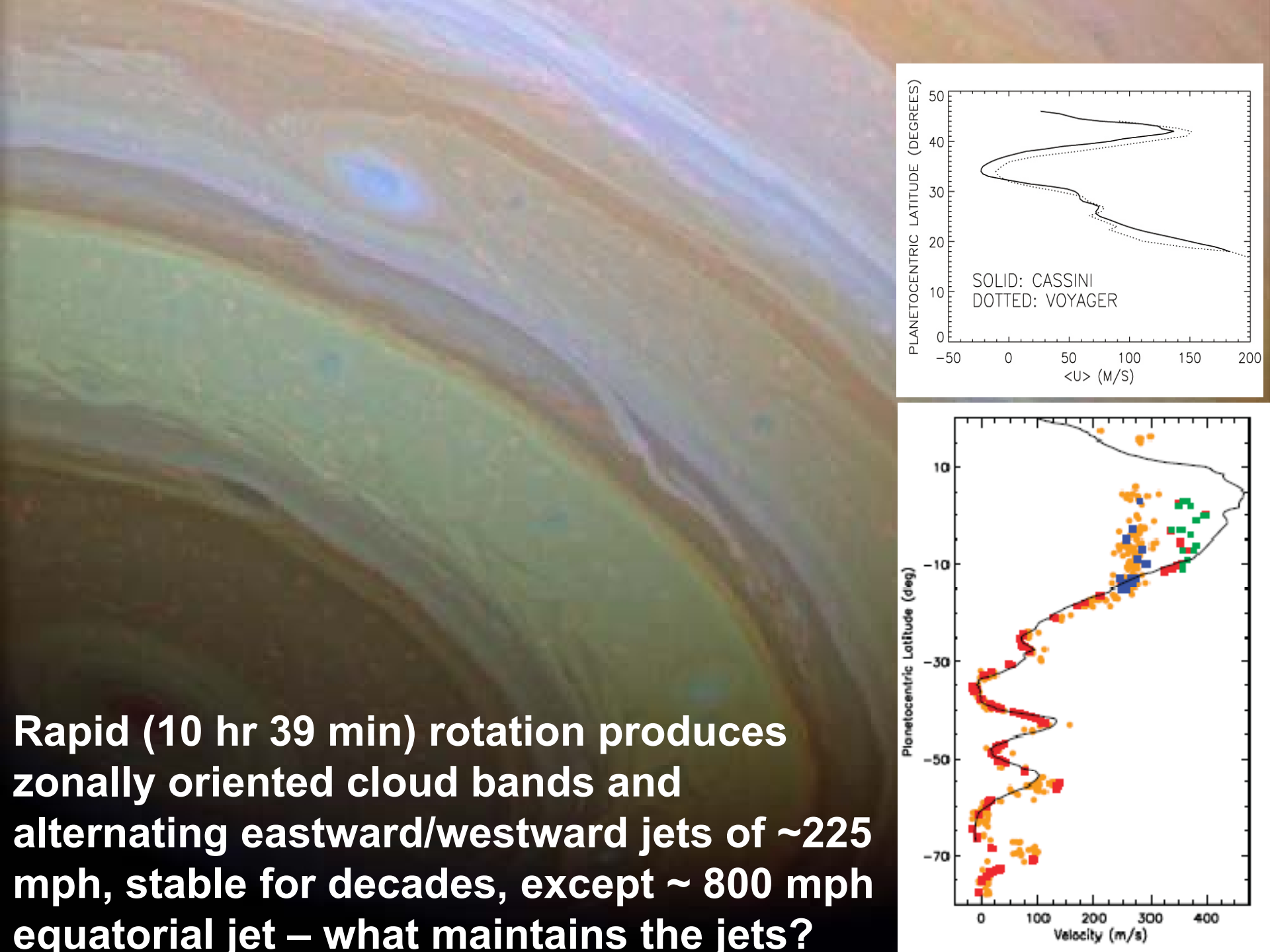
Result is that image contrasts are much greater on Jupiter than on Saturn

(e.g., Voyager: 10x as much wind data on Jupiter vs. Saturn)

To compensate:
- Image in near IR where contrast is greater
- Image repeatedly to build up statistics

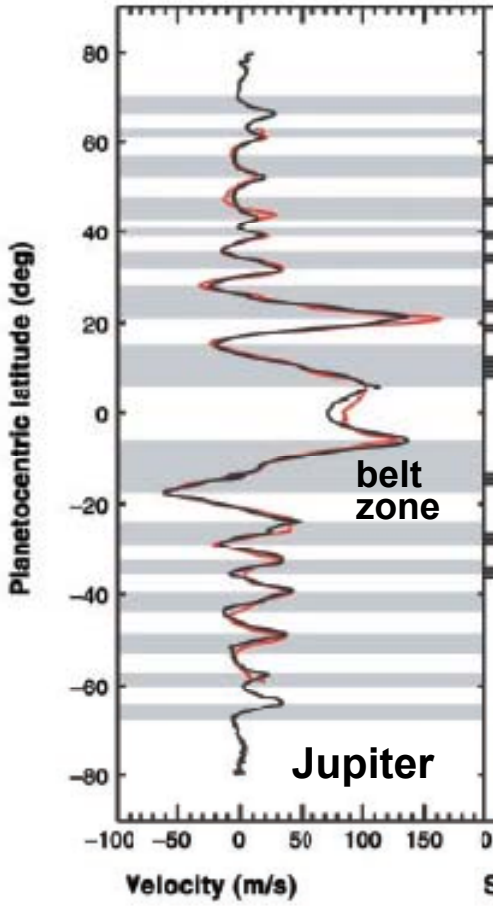


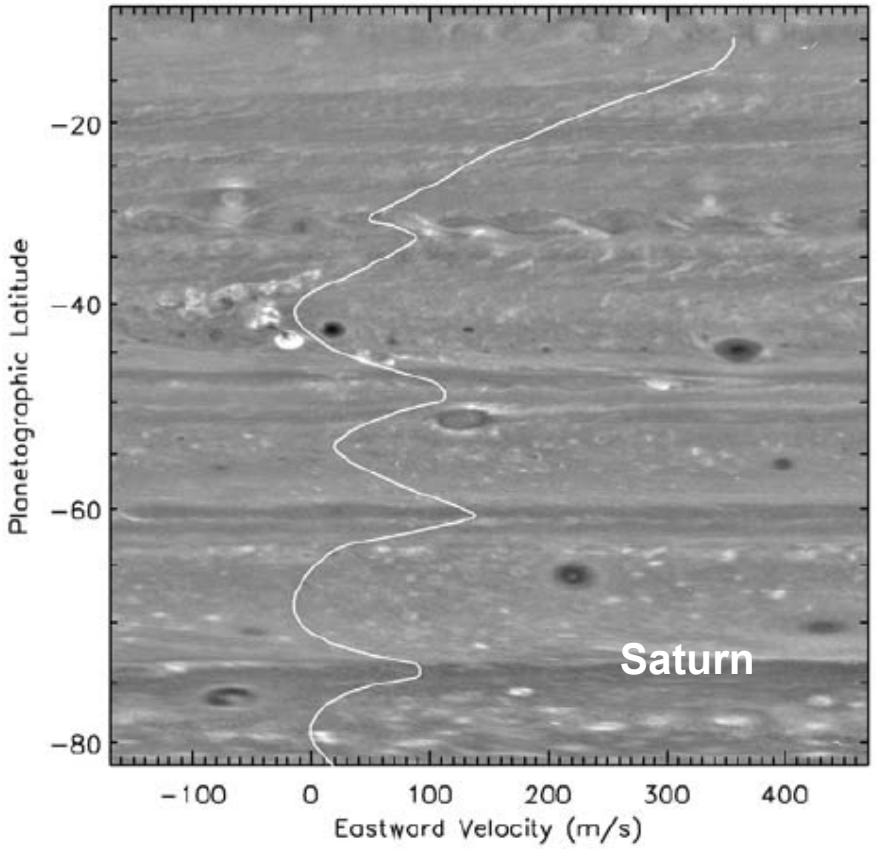
But haze is thicker in Southern (summer) hemisphere – much easier to track winds in Northern Hemisphere right now



Rapid (10 hr 39 min) rotation produces zonally oriented cloud bands and alternating eastward/westward jets of ~225 mph, stable for decades, except ~ 800 mph equatorial jet – what maintains the jets?

Jupiter: zones (bright) → anti-cyclonic shear,
belts (dark) → cyclonic shear
Saturn: More fine structure; if anything,
dark → eastward jets





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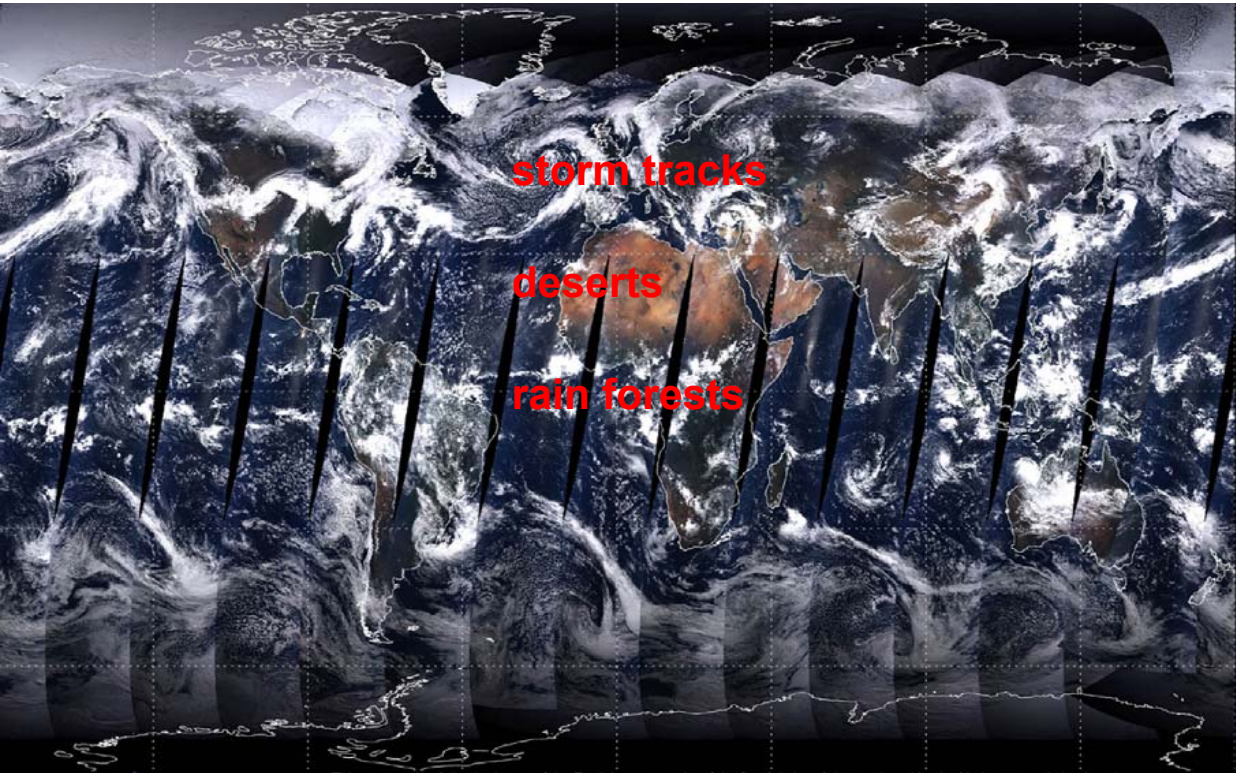
Theories for maintenance of eastward and westward jets

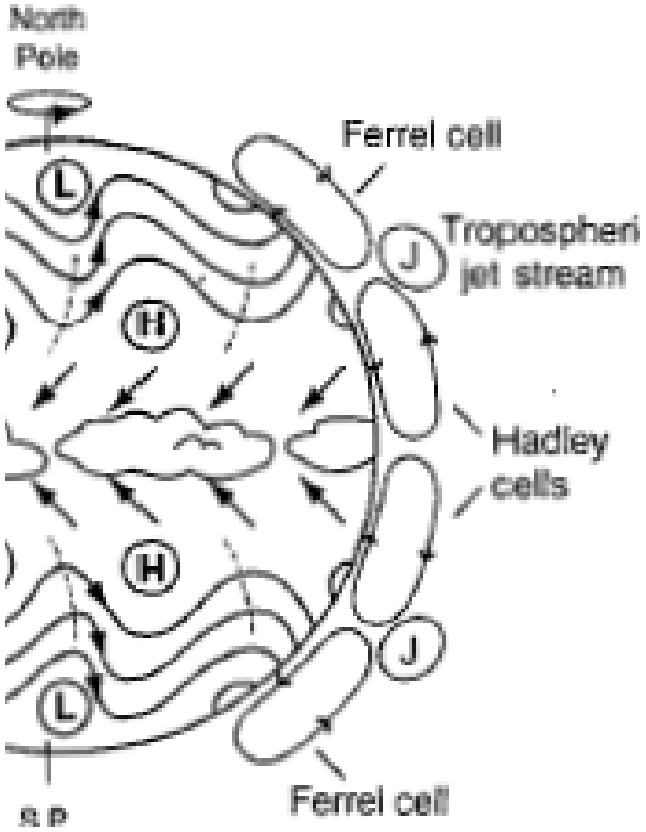
"Weather layer" hypotheses

- **Coriolis force on poleward-drifting air due to cells of rising-sinking motion (like Earth tropics) (Hess and Panofsky, 1951)**
- **Baroclinic instability (like Earth high-low pressure centers) due to latitudinal heating and temperature differences (Williams, 2003; Lian and Showman, 2007)**
- **Pumping by thunderstorms feeds energy into jets (Ingersoll et al., 2000; Li et al., 2006; Showman, 2007)**

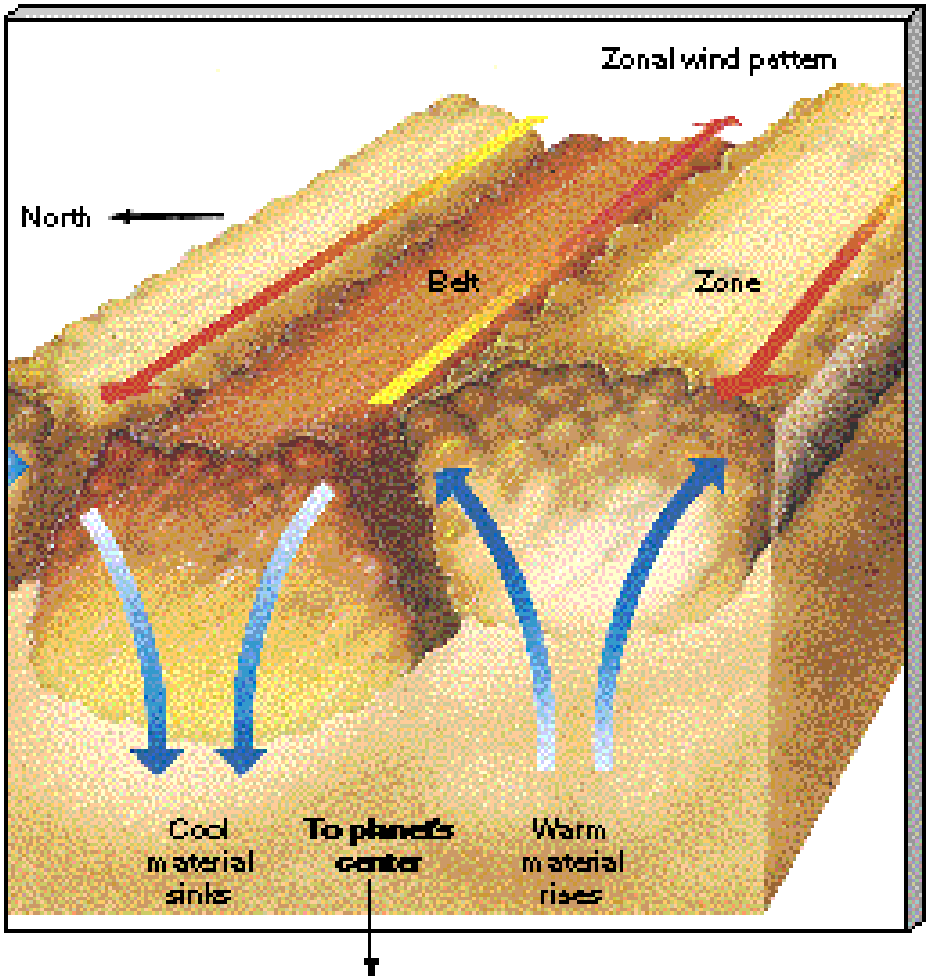
- **Cloud-level manifestation of deep rotating convective cylinders (Busse, 1976; Heimpel and Aurnou, 2007)**

Early observers: Bright "zones" and dark "belts" on jovian planets reminiscent of Earth's own banded cloud structure





Gave rise to traditional view that zones and belts are analogous the Earth's tropical Hadley cell



Rising in warm anti-cyclonic regions ("zones") condenses bright cloud

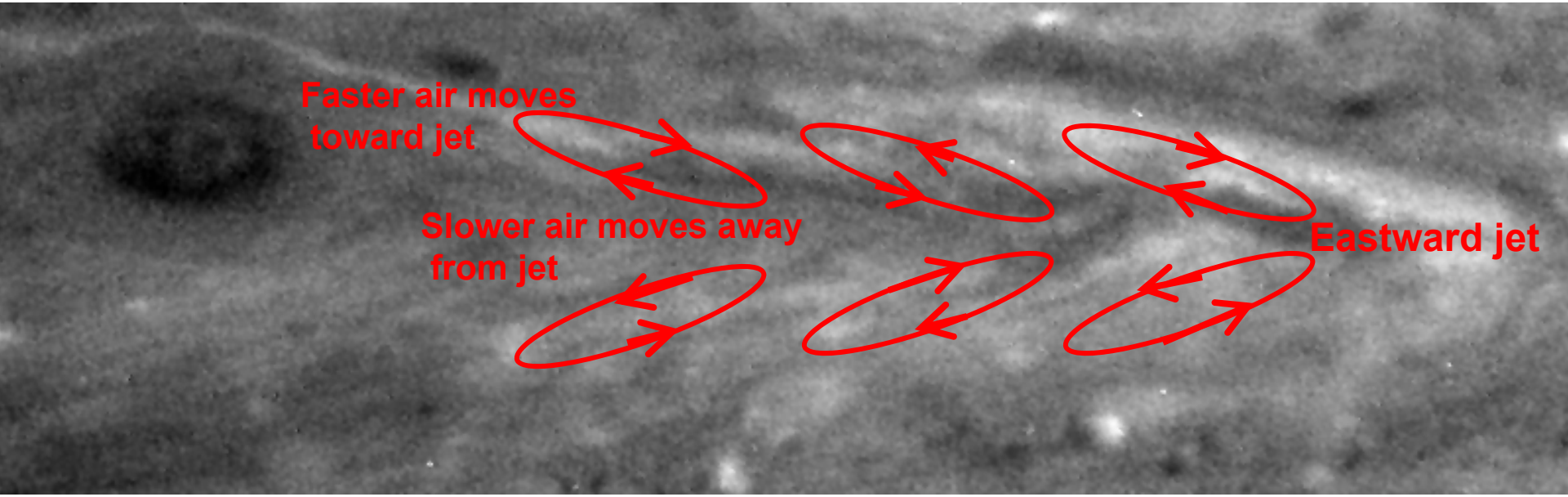
Sinking in cool cyclonic regions ("belts") evaporates cloud

Coriolis force on air drifting from zones to belts deflects air to right (in N.H.) and sustains eastward jets

Smoking gun: Does air rise in zones and sink in belts?

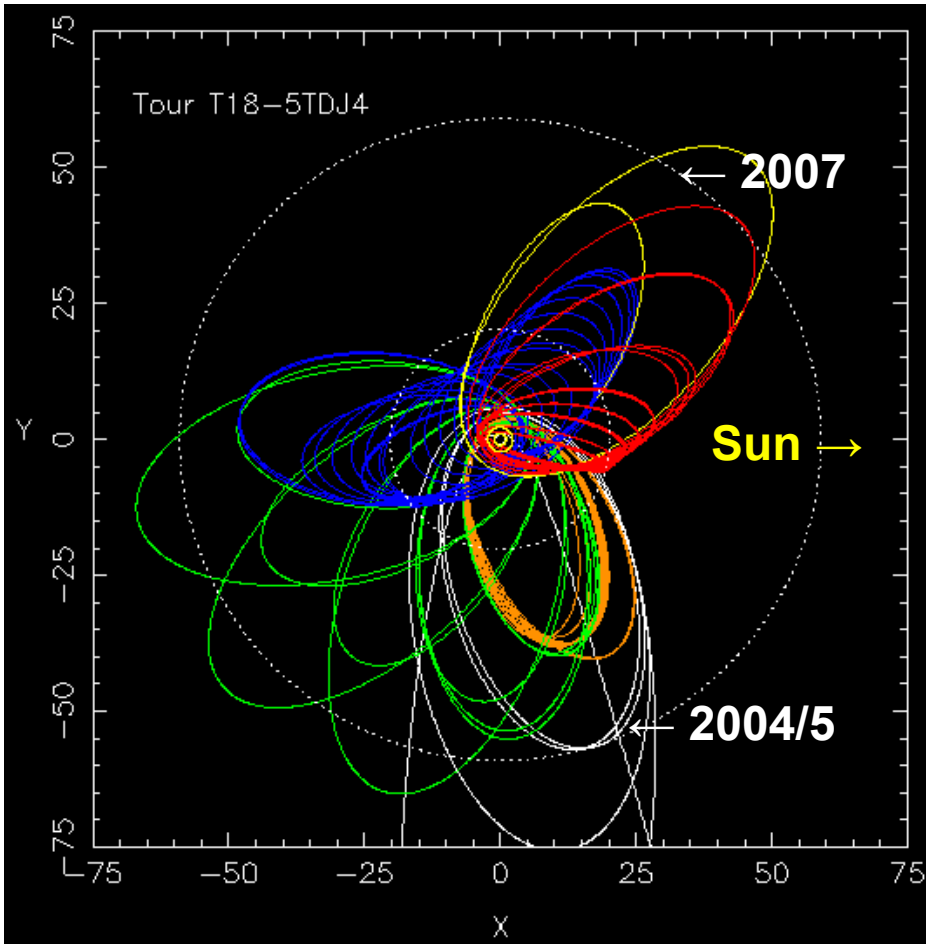
Another possibility: Tilted eddies (disturbances in the mean flow) carry higher-than-average momentum air into jet, accelerating it, and lower-than-average momentum air out of the jet, which also accelerates it

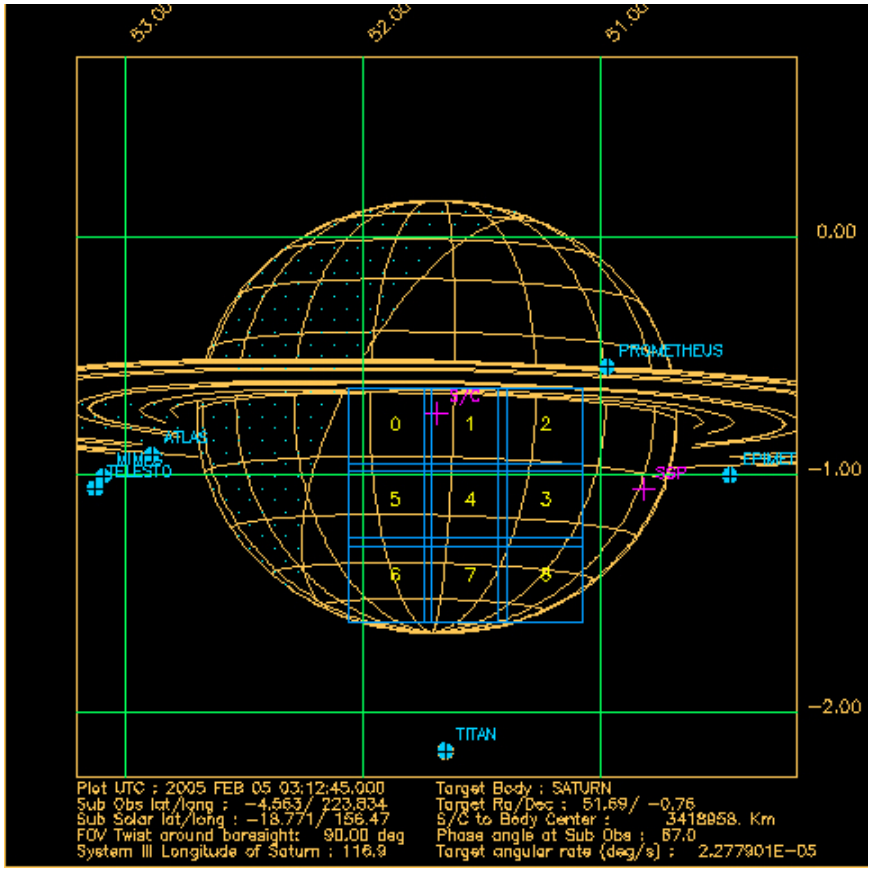
Pumping by thunderstorms, or baroclinic instability



Smoking gun: "Chevron" cloud morphology – but do wind measurements bear this out?

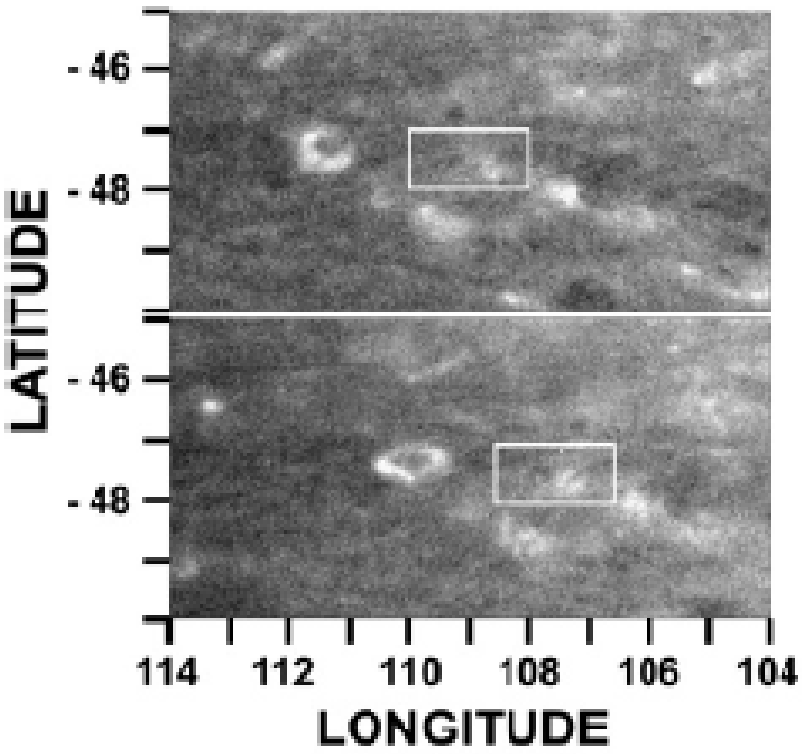
Strategy: Focus on dayside large apoapsis orbits

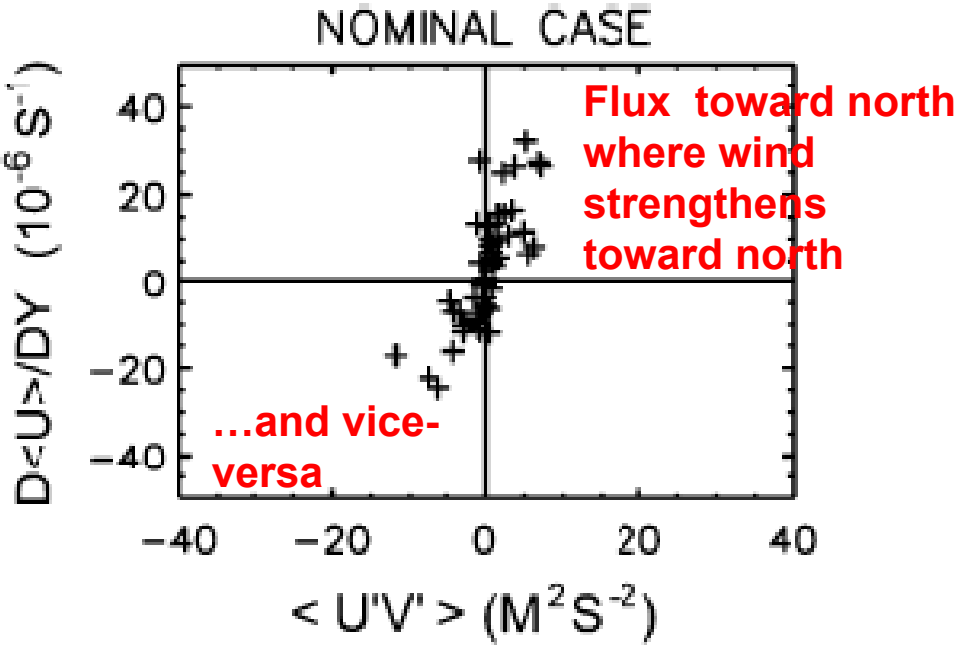




Multiple-frame image mosaics every Saturn rotation in several filters sensitive to different altitudes

ID same feature in images on successive orbits using automated algorithm, measure departures of wind speed in east-west (u') and north-south (v') directions: Are they correlated? If so, only at certain latitudes?





Implies that kinetic energy of eddies is being converted to kinetic energy of mean flow in the jet everywhere

Convective storm detection: Image in continuum filter (weak absorption, sees deep) and methane band filter (strong absorption, sees only to high altitude) simultaneously

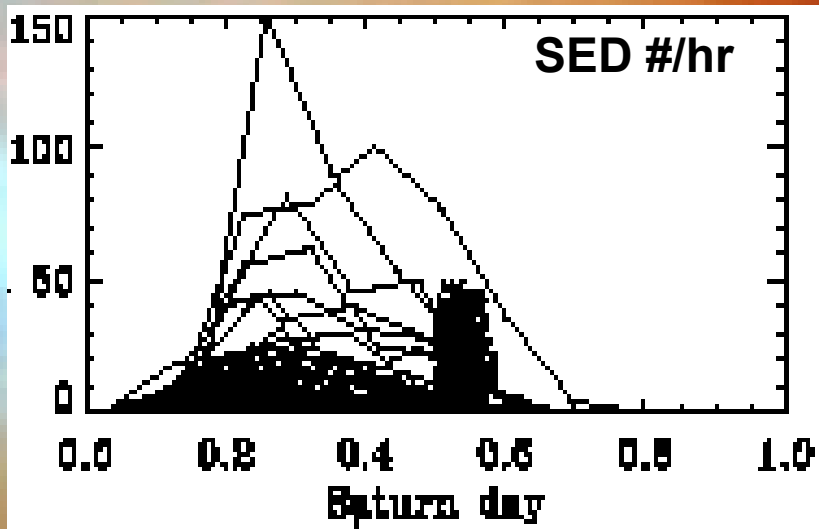
Small, rapidly evolving features bright in both filters are convection → rising motion

Low –level cloud

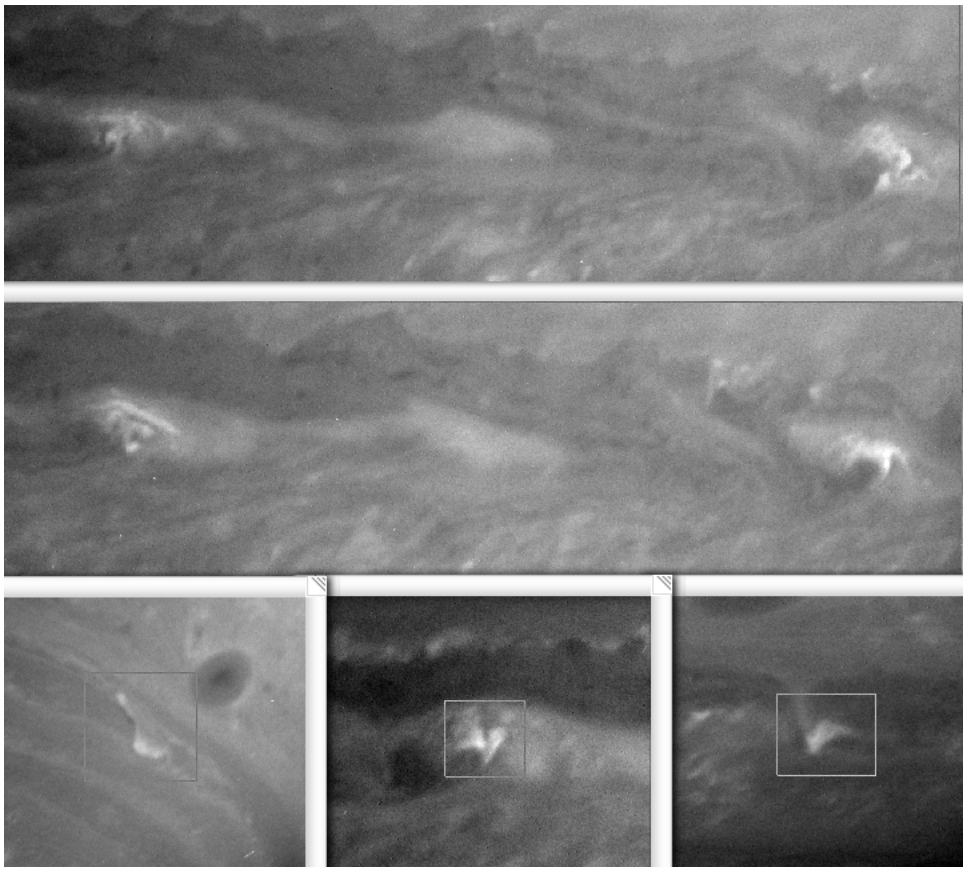
Convective cloud

Thin high cloud

"Dragon storm": Water thunderstorm ~100 miles deep – lightning not detected by cameras, but appearance on disk correlates with Saturn electrostatic discharges

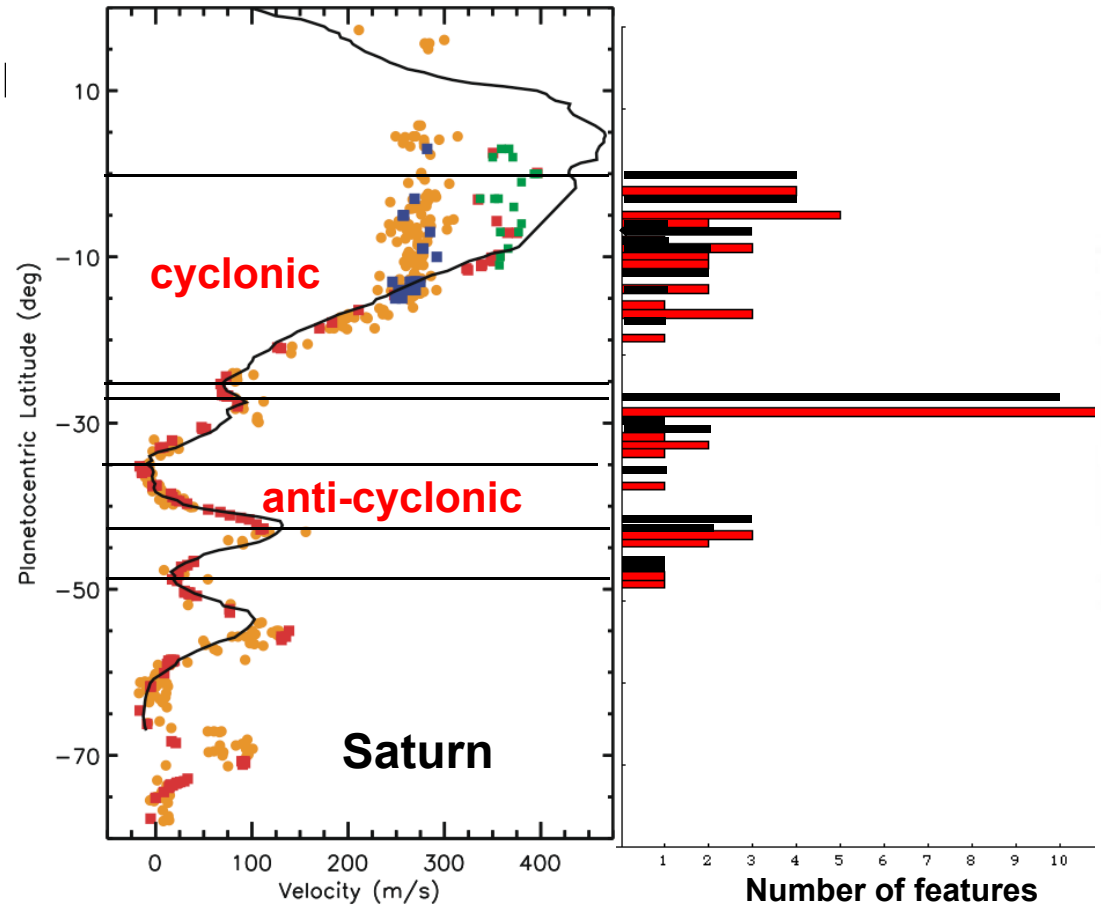


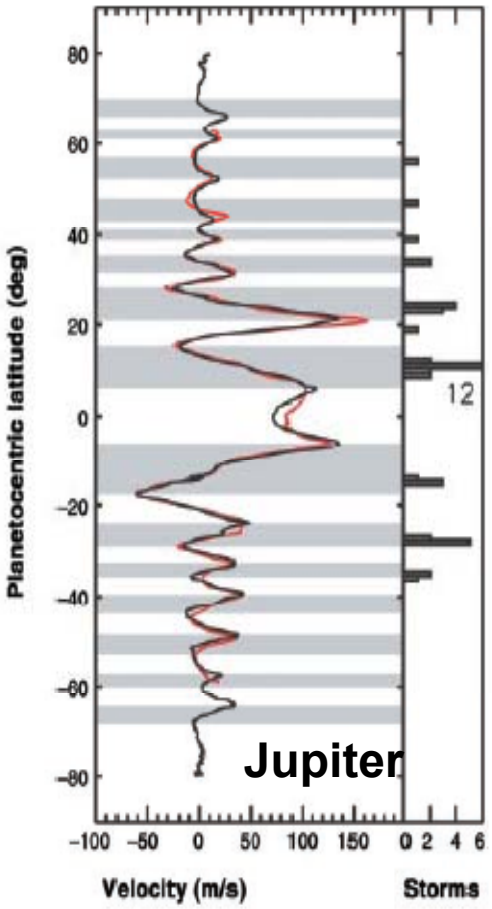
Other examples of Saturn convective storms



Do they occur randomly or in preferred locations?

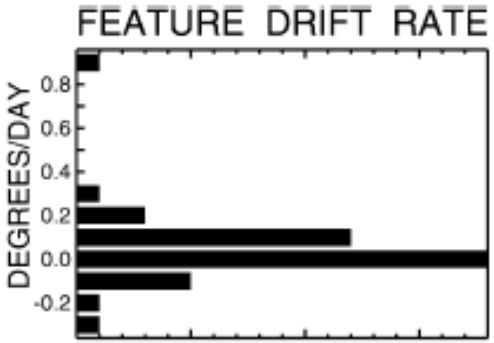
Convective features mostly in cyclonic shear ("belts"), rarely in anti-cyclonic shear ("zones") – so air rises in belts, not zones!

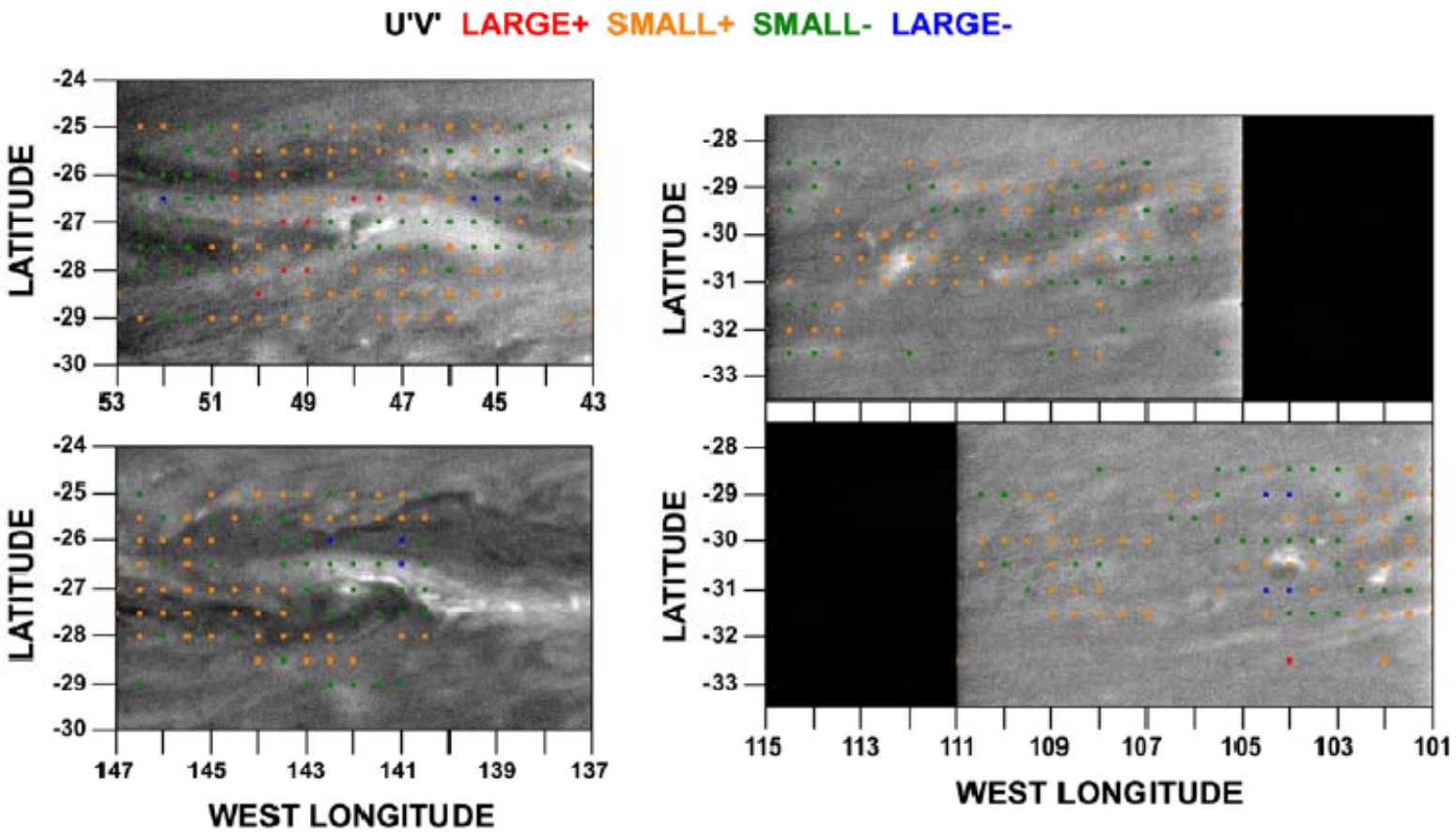




But some storms in E and W jets on Saturn, unlike Jupiter

No sign of preferred drift direction or concentration of large momentum fluxes near convective storms – so probably not the direct source of momentum for the jets





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Scorecard on jet maintenance mechanisms:

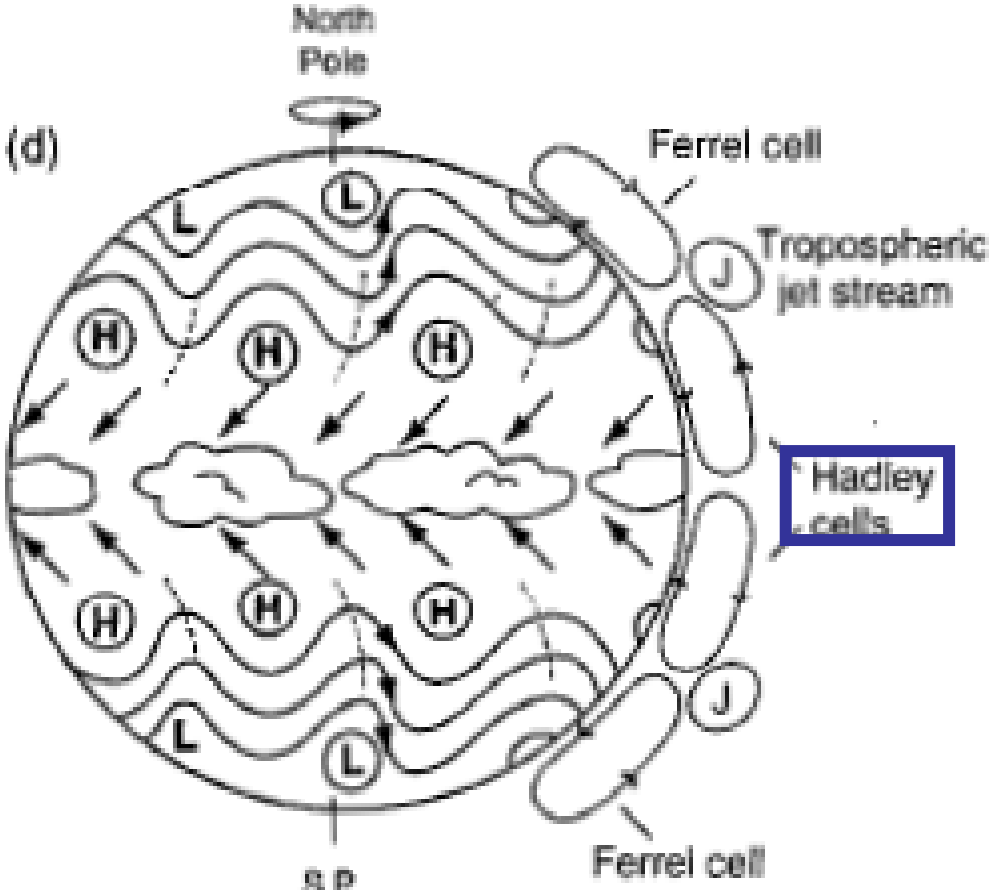
Coriolis force on poleward-drifting air associated with cells of rising-sinking motion (like Earth tropics) – inconsistent with convection in belts rather than zones

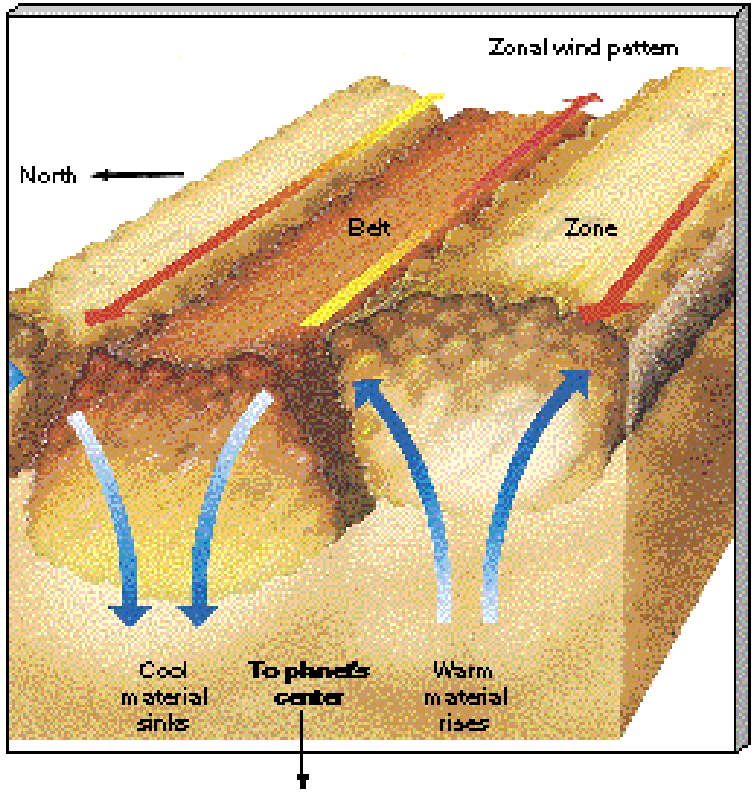
Baroclinic instability (like Earth high-low pressure centers) due to latitudinal temperature differences – consistent with eddy momentum flux into jet from both sides and rising motion in belts

Pumping by thunderstorms feeds energy into jets – no evidence for special behavior near storms, inconsistent with eddy momentum flux on both sides of jets

Cloud-level manifestation of deep rotating convective cylinders – unknown how it would manifest at cloud level other than jet structure itself

Old picture of jovian planet meteorology: Like rising/sinking branches of Earth's Hadley cell





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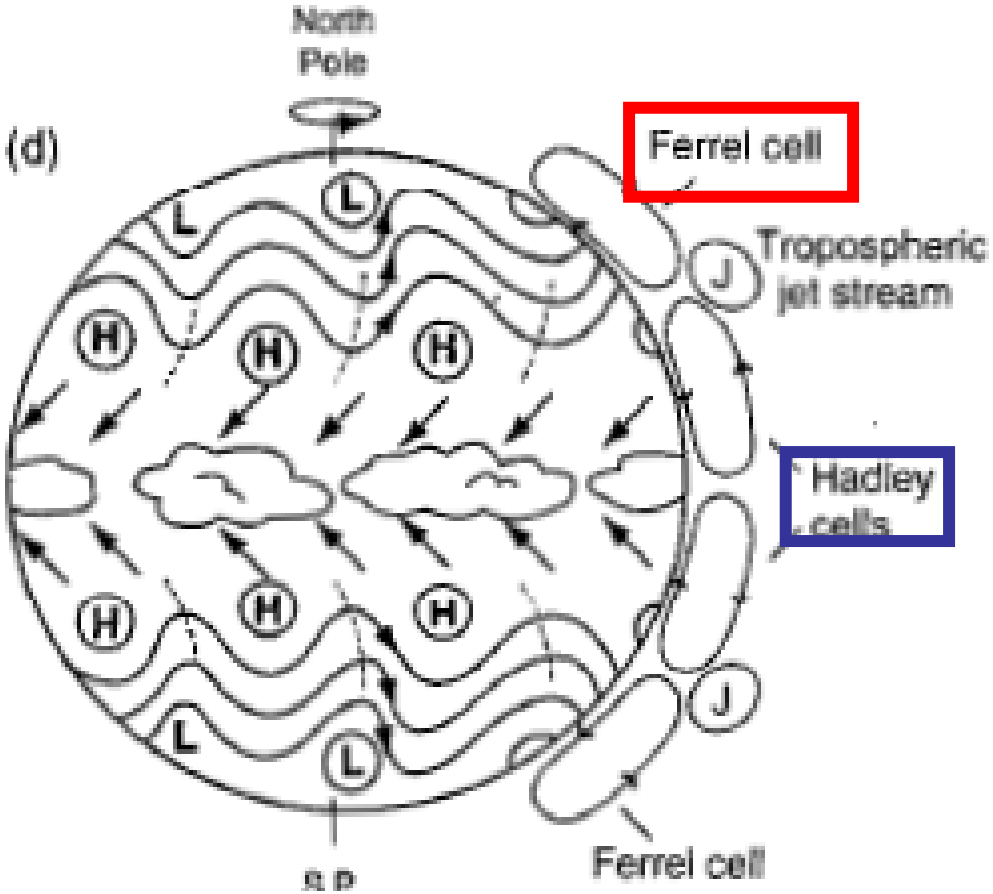

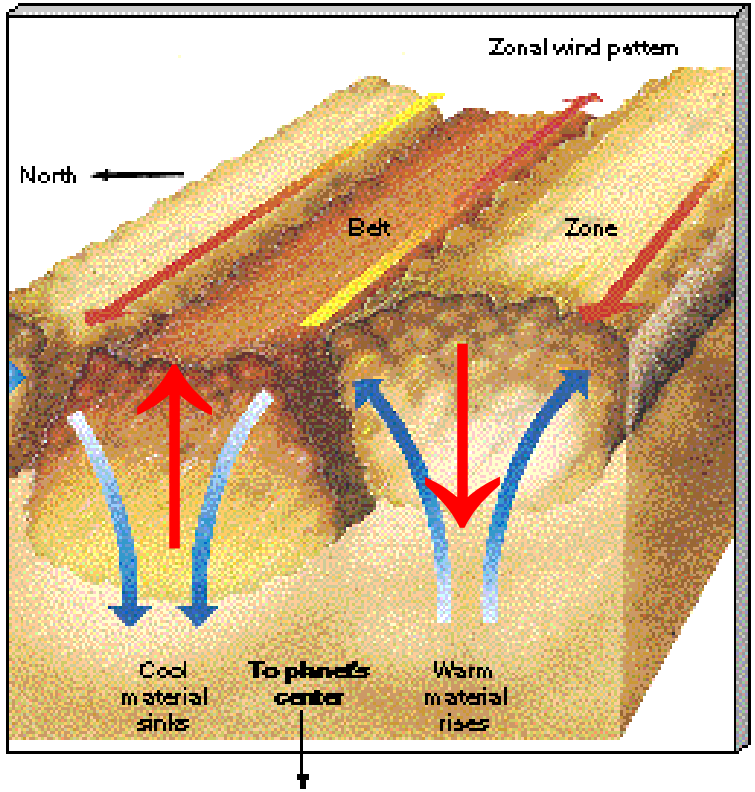

New picture: Like rising/sinking branches of Earth's Ferrel cell driven by baroclinic instability

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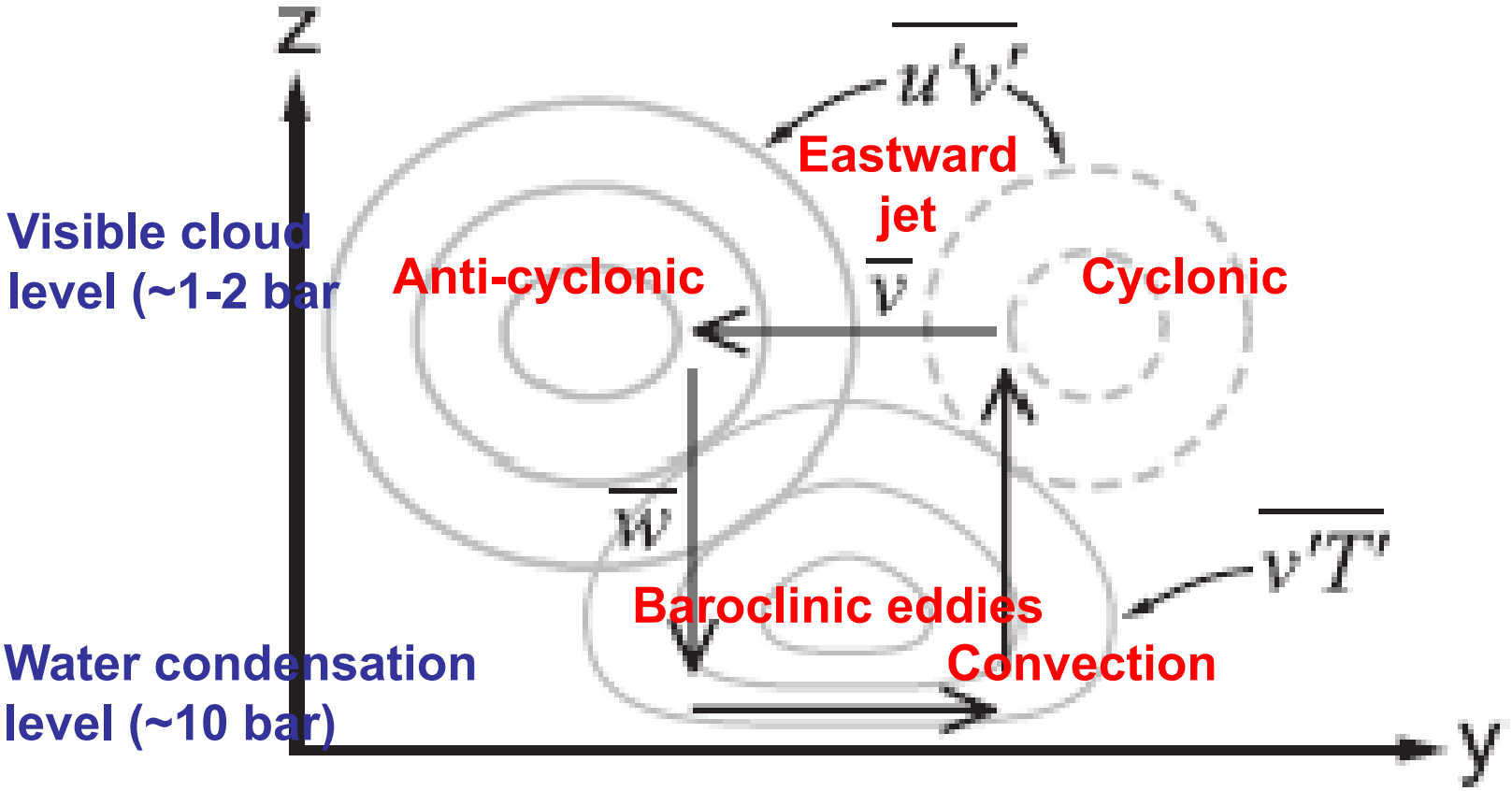
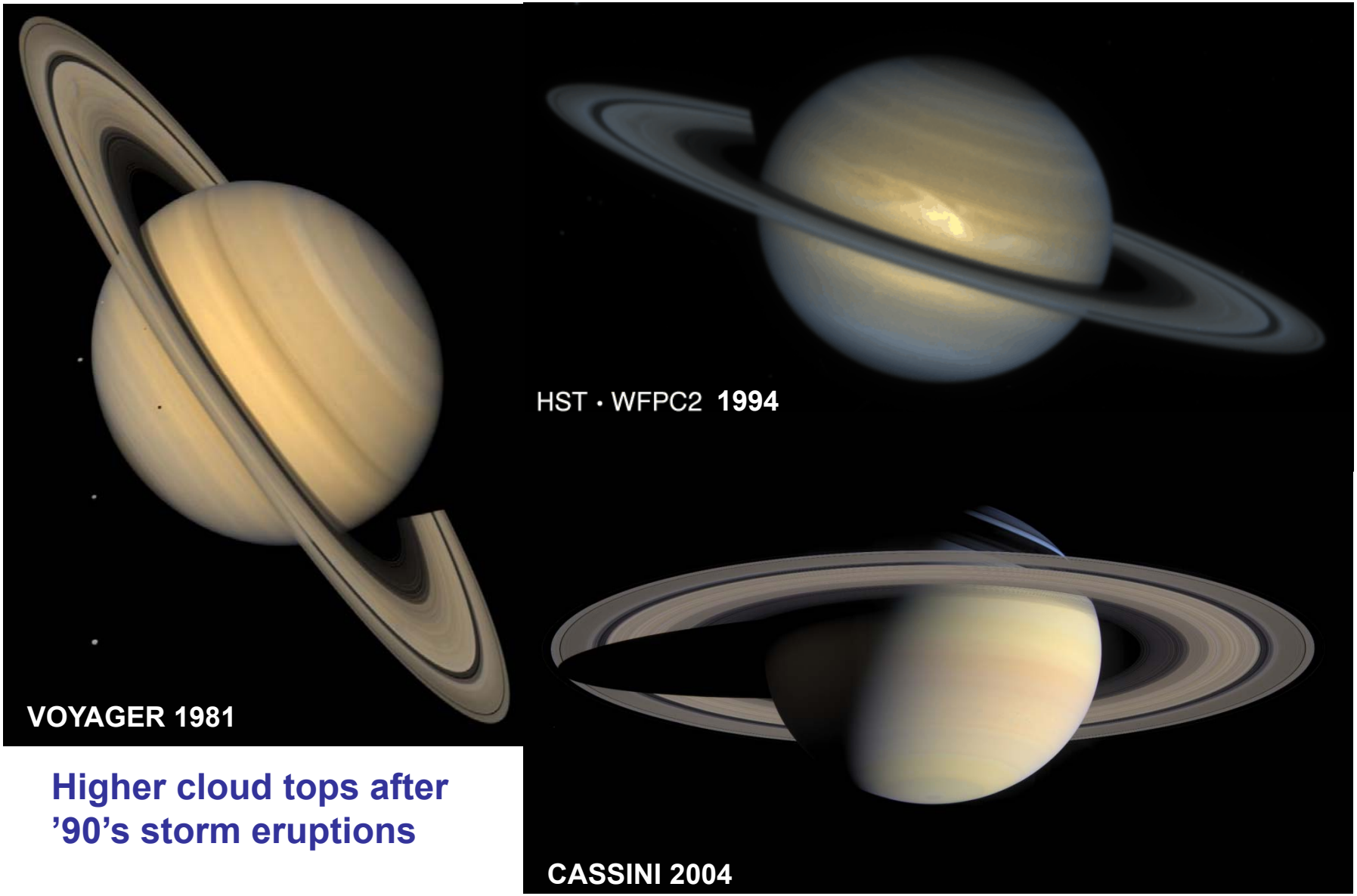
Latitudinal cross-section of Earth's general circulation (Hartmann, 2007) – valid for Jupiter and Saturn too?

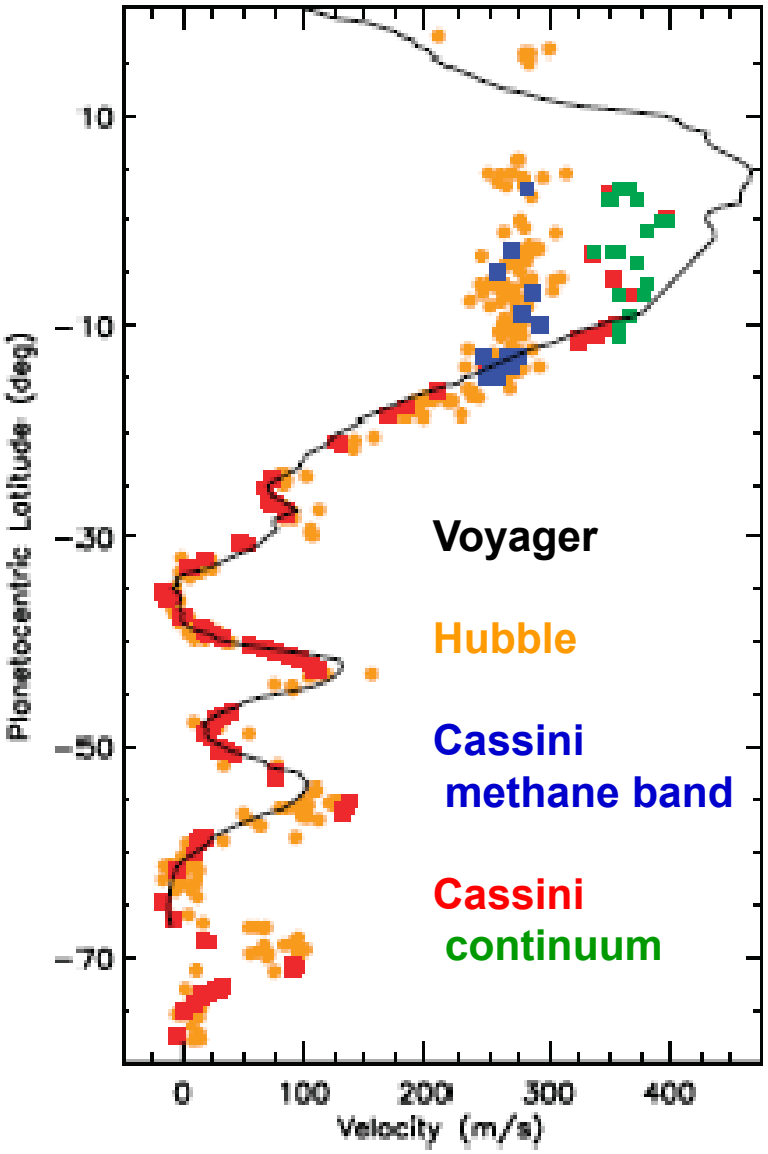


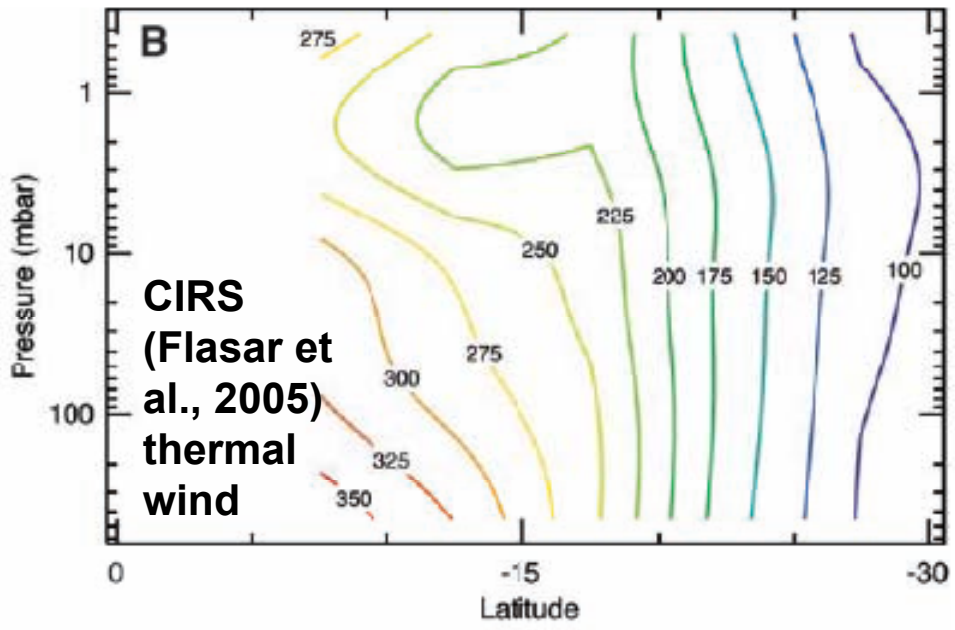
Changes in Saturn's equatorial zone over time



Higher cloud tops after '90's storm eruptions

Equatorial wind speed changes over time: Real or artifact?





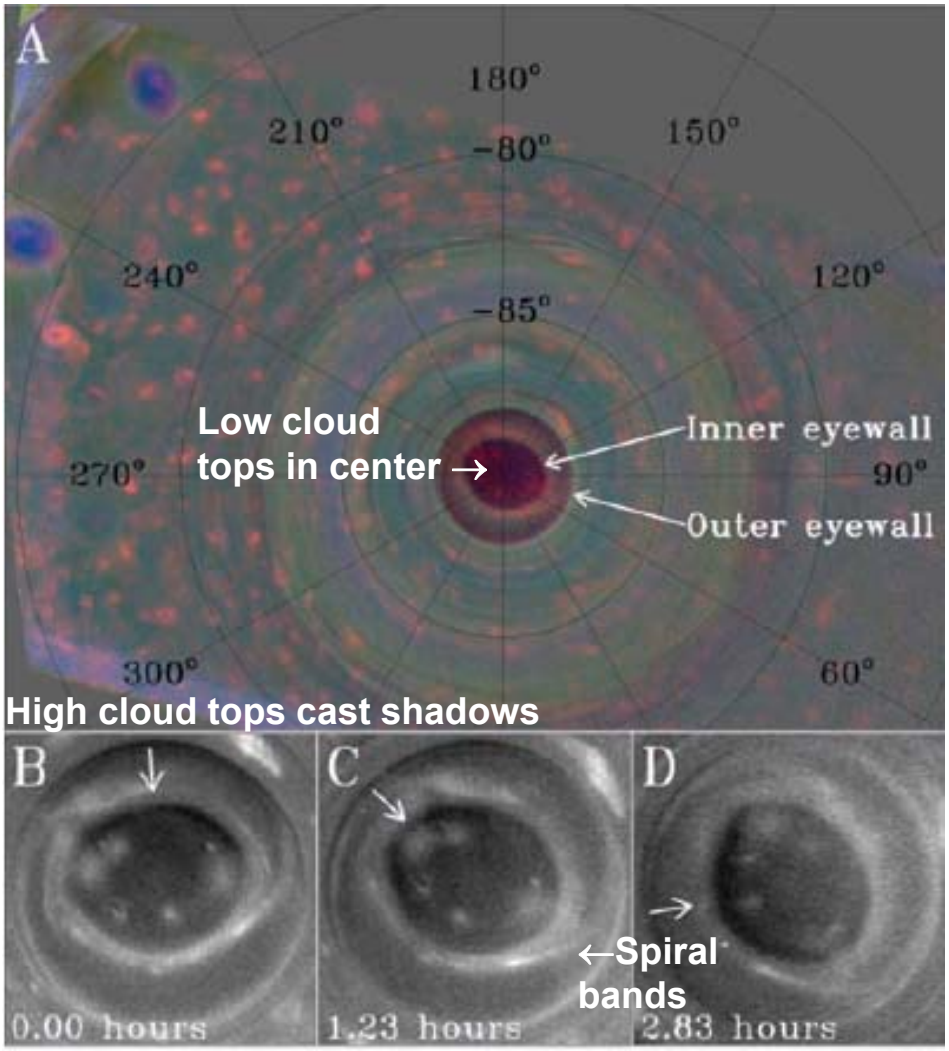
Hubble reports much slower winds than Voyager

Cassini methane band matches Hubble, continuum winds much stronger

So mostly an artifact of higher cloud top and wind decreasing with height?

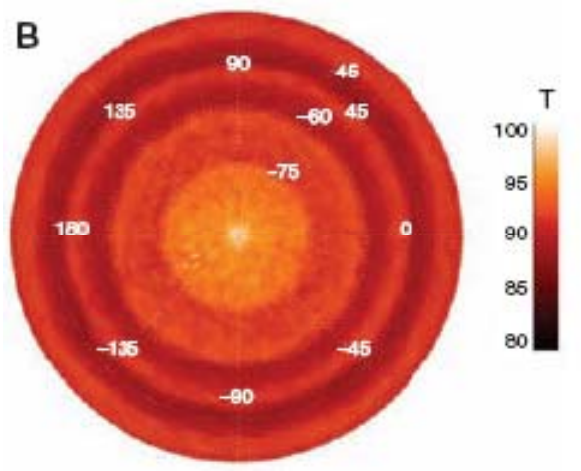
Convection can cause some weakening of wind (Sayanagi and Showman, 2007)

Saturn's south polar vortex (Dyudina et al. 2008)

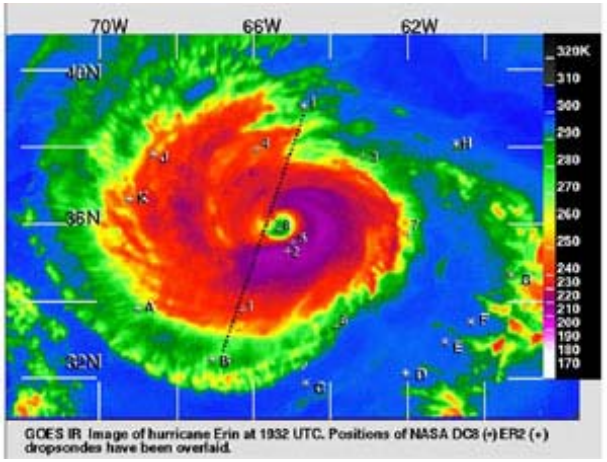


Is it a hurricane?

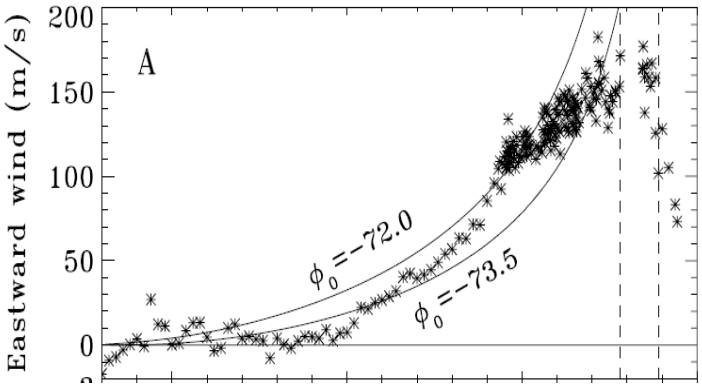
Saturn



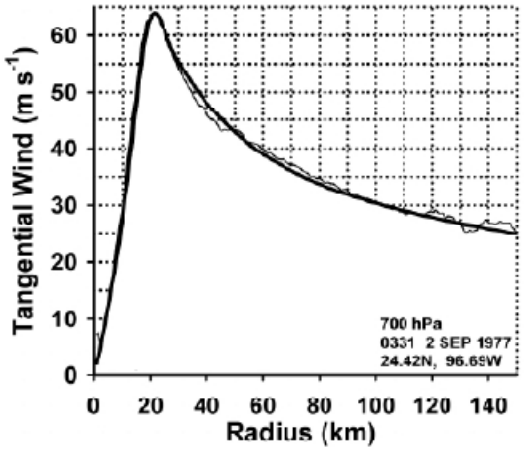
Earth



√ "Warm core" in center "eye" (maybe)



√ Winds increase toward center up to "eyewall"



But…

× No ocean underneath to provide energy source

× Fixed spatially, maybe long-lived, rather than propagating and transient

… so probably not

Conclusions

- General circulation of the jovian planets may indeed be an analogy to Earth…but to Earth's midlatitudes rather than its tropics
- Wind-albedo relationship on Saturn yet to be understood
- Dramatic equatorial changes in clouds and perhaps winds on Saturn needs to be understood…Seasonal shading by rings destabilizing upper levels? Propagating waves?
- South polar vortex hurricane-like in its organization but not in its source