Morphological Characteristics and Changes in Jupiter's Northern Circumpolar Cyclones

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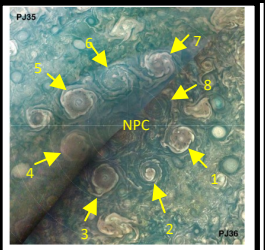
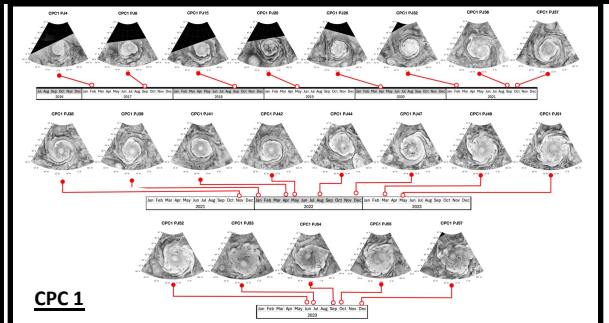


Filled: Example: CPC #1. Characterized by a bright core, sometimes found with anticyclonic circulation in the core, with a relatively uniform stratiform cloud deck outward of the core. Periphery of cyclone is bounded by bright clouds reminiscent of a circular saw blade. Lightning detected during PJ31 in one such cloud suggests convective activity is involved in forming/maintaining these bright features. Stratiform cloud deck often contains small holes and/or thinner regions allowing thermal radiation to escape to space. Holes may be formed by shear instability on the periphery from gaps between "blade" clouds, and subsequently transported inwards.

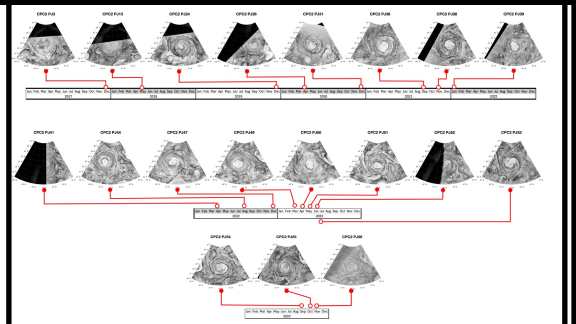
Chaotic/Spiral: Example: CPC #2 prior to PJ 36, and CPC #8, and the North Polar Cyclone. Characterized by multiple spiral arms with a flocculent appearance composed of small relatively bright cumuliform clouds. Overall morphology reminiscent of a spiral galaxy viewed from above. In thermal infrared (JIRAM), the multiple spiral arms all appear relatively dark, suggesting these features are optically thicker than JunoCam images might otherwise suggest.



CPC 1

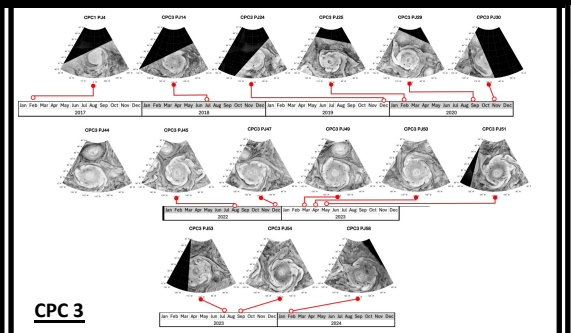
CPC 1 has maintained the "filled" or circular-saw "bladed" morphology throughout the mission.
Rapid increase in size occurred around PJ 49.
JunoCam (JIRAM)-dark (bright) features in the interior may be as a result of cloud-free lanes along the periphery being advected inward and pinching into smaller features.
Circular bright core is not always apparent. Core brightness varies relative to the low-brightness, presumably stratiform cloud deck surrounding it and extending to the brighter "blade" formations on the periphery.
Anticyclonic circulation occasionally observed in the bright core of "filled" CPCs suggests upwelling.

PJ	Date	PJ	Date	PJ	Date	PJ	Date	PJ	Date	PJ	Date
1	8/27/16	13	5/24/18	25	2/17/20	37	10/16/21	49	3/1/23	61	5/12/24
2	10/19/16	14	7/16/18	26	4/10/20	38	11/29/21	50	4/8/23	62	6/14/24
3	12/11/16	15	9/7/18	27	6/2/20	39	1/12/22	51	5/16/23	63	7/17/24
4	2/2/17	16	10/29/18	28	7/25/20	40	2/25/22	52	6/23/23	64	8/18/24
5	3/27/17	17	12/21/18	29	9/16/20	41	4/9/22	53	7/31/23	65	9/20/23
6	5/19/17	18	2/12/19	30	11/8/20	42	5/23/22	54	9/7/23	66	10/23/24
7	7/11/17	19	4/6/19	31	12/30/20	43	7/5/22	55	10/15/23	67	11/25/24
8	9/1/17	20	5/29/19	32	2/21/21	44	8/17/22	56	11/22/23	68	12/28/24
9	10/24/17	21	7/21/19	33	4/15/21	45	9/29/22	57	12/30/23	69	1/30/25
10	12/16/17	22	9/12/19	34	6/8/21	46	11/6/22	58	2/3/24	70	3/4/25
11	2/7/18	23	11/3/19	35	7/21/21	47	12/15/22	59	3/7/24	71	4/6/25
12	4/1/18	24	12/26/19	36	9/2/21	48	1/22/23	60	4/9/24	72	5/8/25



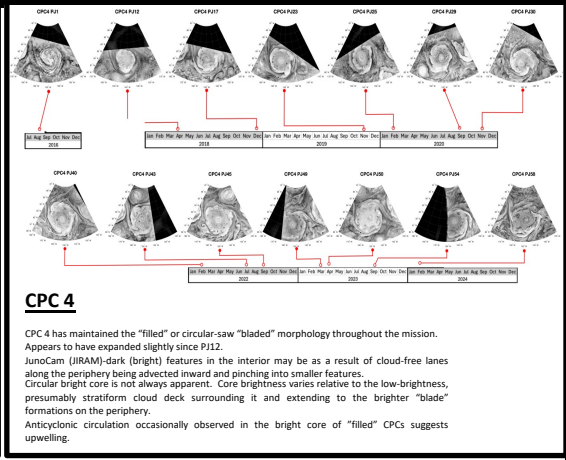
CPC 2

CPC 2 has transitioned away from the "chaotic/spiral" morphology towards a more "filled" morphology.
Transition is partial and may represent a hybrid morphology (e.g., PJ44)
The core has also transitioned from low cloud opacity to high cloud opacity.
The bright interior may be a result of upwelling forming a cloud deck that obscures an existing spiral structure?
Overall decrease in size



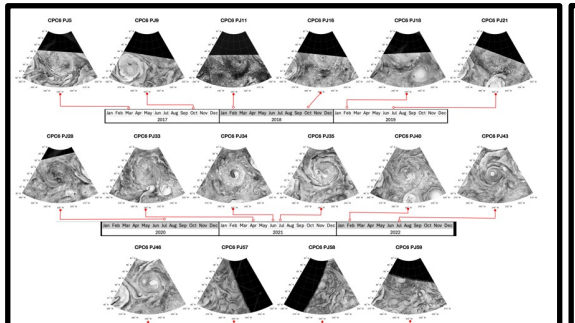
CPC 3

CPC 3 has maintained the "filled" or circular-saw "bladed" morphology throughout the mission.
JunoCam (JIRAM)-dark (bright) features in the interior may be as a result of cloud-free lanes along the periphery being advected inward and pinching into smaller features.
Circular bright core is usually apparent and varies in brightness relative to the low-brightness and presumably stratiform cloud deck, surrounding it and extending to the brighter "blade" formations on the periphery.
Anticyclonic circulation occasionally observed in the bright core of "filled" CPCs suggests upwelling.
Relatively low brightness stratiform cloud deck between core and periphery (e.g. PJ 54) may be thinner and/or located slightly lower in the atmosphere.



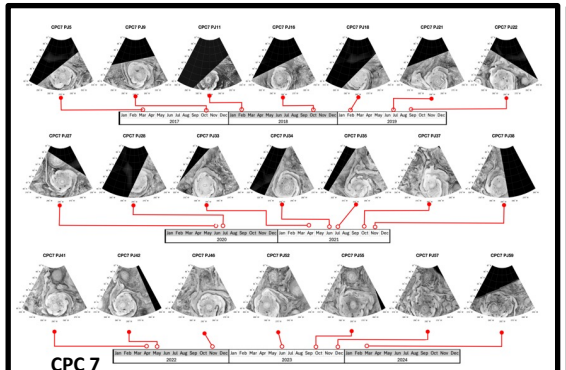
CPC 4

CPC 4 has maintained the "filled" or circular-saw "bladed" morphology throughout the mission.
Appears to have expanded slightly since PJ12.
JunoCam (JIRAM)-dark (bright) features in the interior may be as a result of cloud-free lanes along the periphery being advected inward and pinching into smaller features.
Circular bright core is not always apparent. Core brightness varies relative to the low-brightness, presumably stratiform cloud deck surrounding it and extending to the brighter "blade" formations on the periphery.
Anticyclonic circulation occasionally observed in the bright core of "filled" CPCs suggests upwelling.



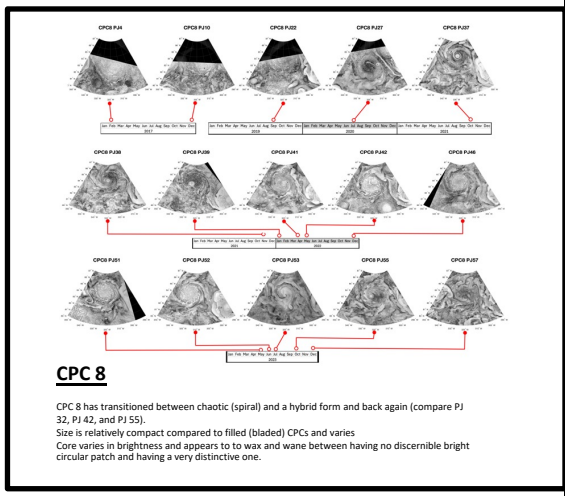
CPC 6

CPC 6 has switched morphologies from chaotic (spiral) to a hybrid form.
Core is rather dynamic in that bright and dark features sometimes coexist in close proximity (e.g., PJ 34)
Core occasionally shows multiple bright features in close proximity (e.g., PJ 35, 46)
CPC 6 is generally compact relative to filled (bladed) CPCs.



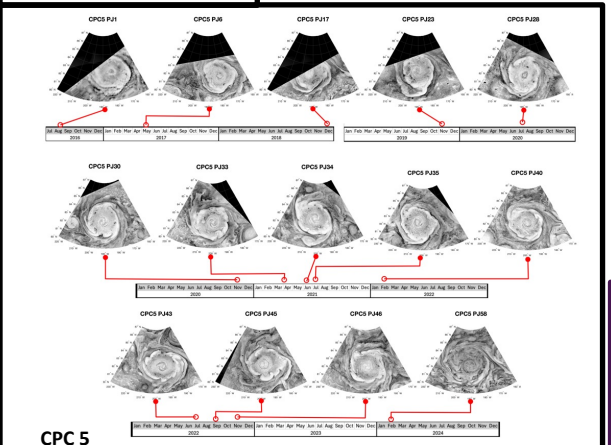
CPC 7

CPC 7 has maintained the "filled" or circular-saw "bladed" morphology throughout the mission.
JunoCam (JIRAM)-dark (bright) features in the interior may be as a result of cloud-free lanes along the periphery being advected inward and pinching into smaller features.
Circular bright core is usually apparent and varies in brightness relative to the low-brightness and presumably stratiform cloud deck, surrounding it and extending to the brighter "blade" formations on the periphery.
Anticyclonic circulation occasionally observed in the bright core of "filled" CPCs suggests upwelling.
Position of CPC7 has the greatest variation in longitude, and the lowest latitude.
Cloud-free lanes along the periphery being advected inward and pinching into smaller features (compare PJ 43 and 46)



CPC 8

CPC 8 has transitioned between chaotic (spiral) and a hybrid form and back again (compare PJ 32, PJ 42, and PJ 55).
Size is relatively compact compared to filled (bladed) CPCs and varies
Core varies in brightness and appears to to wax and wane between having no discernible bright circular patch and having a very distinctive one.

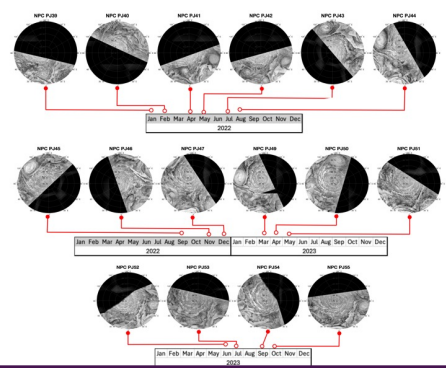


CPC 5

CPC 5 has maintained the "filled" or circular-saw "bladed" morphology throughout the mission.
JunoCam (JIRAM)-dark (bright) features in the interior may be as a result of cloud-free lanes along the periphery being advected inward and pinching into smaller features.
Circular bright core is usually apparent and varies in brightness relative to the low-brightness and presumably stratiform cloud deck, surrounding it and extending to the brighter "blade" formations on the periphery.
Anticyclonic circulation occasionally observed in the bright core of "filled" CPCs suggests upwelling.
Distortion into a more elliptical shape followed by return to more circular shape.
Relatively low brightness stratiform cloud deck between core and periphery (e.g. PJ 46) may be thinner and/or located slightly lower in the atmosphere.

Next Steps

Complete mapping of each CPC for all available JunoCam and JIRAM images
Automate or manually outline and compute the areal coverage, of each cloud type in each map.
Where sufficient shadowing exists, compute cloud heights.
Perform spectroscopic retrievals for each available JIRAM data set for each CPC. Conduct NEMESIS[8] retrievals to compute optical thicknesses for each JIRAM data set for each CPC.
Integrate MWR CPC data sets. Perform brightness temperature retrievals for each CPC[8]. Conduct lightning search from MWR brightness temperature anomalies [10]



NPC

Morphologically consistent in holding a chaotic (spiral) form. No other spiral CPC has maintained its morphology as consistently has NPC
Position oscillates in latitude and longitude.
No discernable core feature (bright or dark circular patch) observed.
Appears relatively dark in JIRAM (not shown here), suggesting high cloud opacity with JunoCam dark lanes appearing slightly brighter in JIRAM.

Discussion

The Northern CPCs have remained in a remarkably stable configuration containing 8 CPCs around a 9th slightly offset from the pole itself [1,2]. Despite intruding vortices and the tendency for like-signed vortices to merge when in close proximity, the cyclones generally oscillate around positions that slowly drift westward. Some latitudinal oscillation has also been observed. Stability simulations and modeling[6] have indicated that multiple CPCs on Jupiter can be supported, unlike the case for Saturn where only one cyclone at each pole exists.

The appearance and, to a lesser extent, the size of the CPCs are not the same. For example, CPC #1 has recently expanded (compare JunoCam images PJ47 & PJ52). CPC #2 appears to have shrunk in size (Compare JunoCam images PJ14 and PJ47) and has changed from a chaotic/spiral morphology to a filled morphology. CPCs #6 & #8 have also started transforming from a chaotic/spiral morphology to a filled morphology, although #8 may be shifting back towards its usual chaotic/spiral morphology. This change in appearance may be analogous to the transition of a brown-barge cyclone to a folded filamentary region occasionally observed in the low and mid-latitudes[7], although the process may be slower in the polar regions. This transition is poorly understood both in the polar regions and the low/mid-latitudes. Interestingly, no filled CPCs have been observed transforming into a chaotic/spiral morphology. This begs the question "is the chaotic/spiral morphology is unstable over long periods whereas filled CPCs are a more stable morphology?" If so, why?

Characterizing the size, morphology, areal cloud coverage, composition, and optical thicknesses of the stratiform cloud decks, small-scale cumuliform clouds, number and size of the blade-like clouds, and the cores of filled CPCs is a first step towards understanding how and why these cyclones change. Detailed maps such as those shown in Section 2 will be employed to measure these characteristics. JIRAM images and spectroscopy retrievals will allow optical thicknesses to be estimated that may provide clues to how the CPCs may be changing at depth, providing clues and "ground-truth" for modeling efforts to explain the underlying cloud and storm dynamics involved in creating and forming these features. The microwave radiometer (MWR) is now beginning to resolve the CPCs, which will also reveal what processes are at work in these CPCs and how deep they extend. Future perijoves featuring smaller MWR beam footprints in the north polar latitudes may reveal if lightning is more prevalent in one type of CPC vs. the other, again, potentially providing dynamical clues to processes at work in the CPCs.