SGS6833: 대기과학

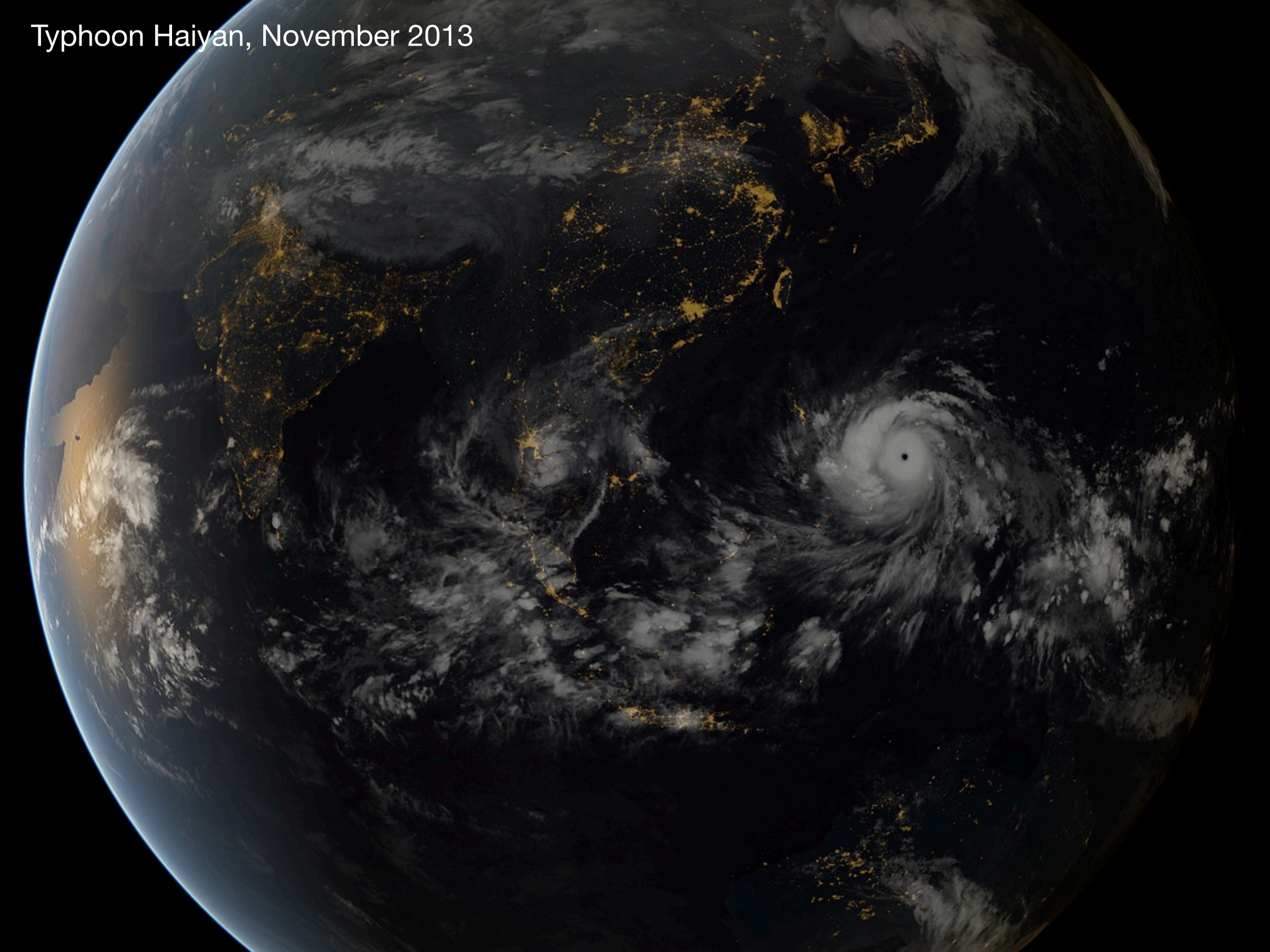
12주 차 강의자료

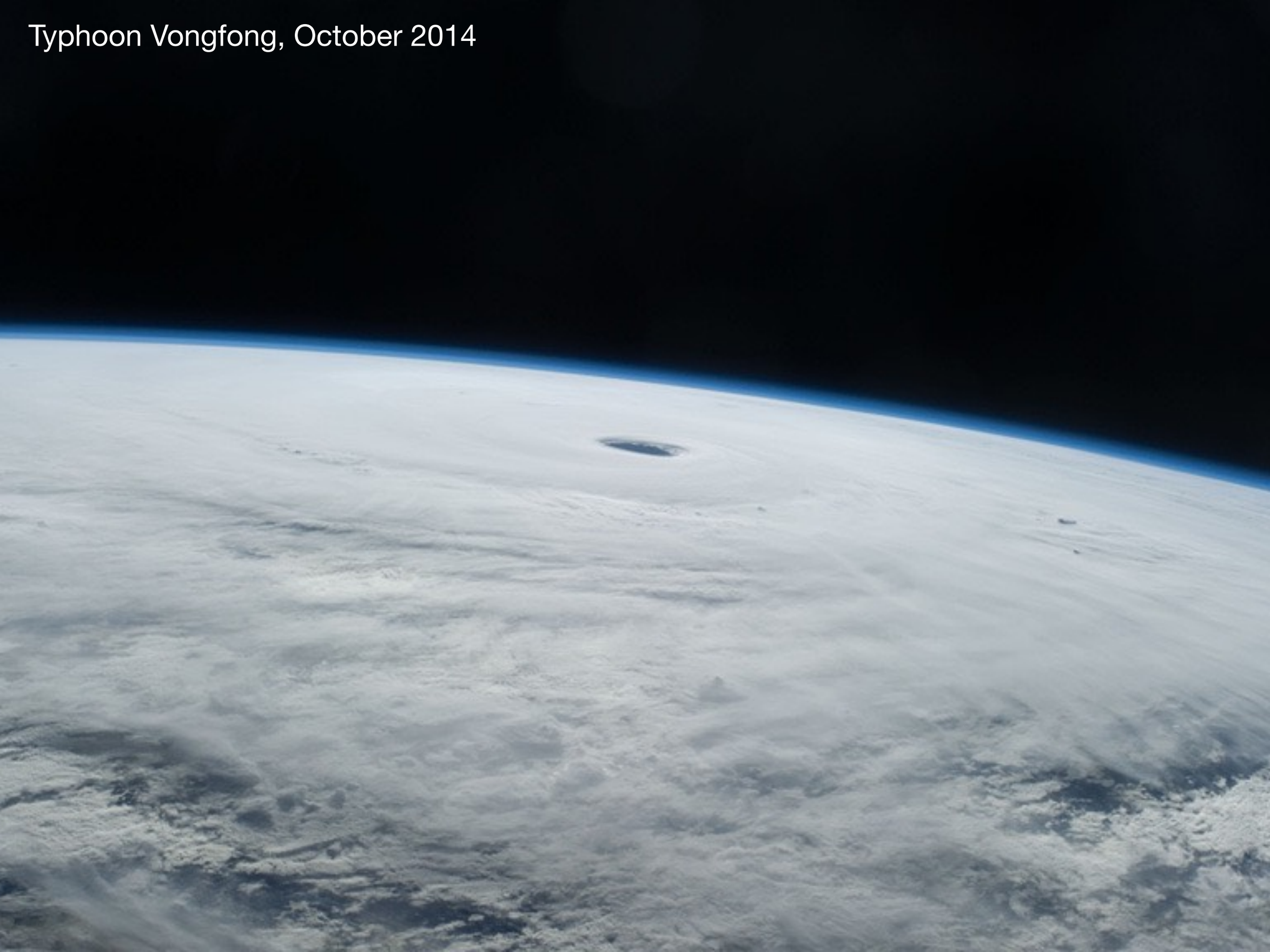
지난시간

- 일기예보
- Thunderstorms and tornadoes

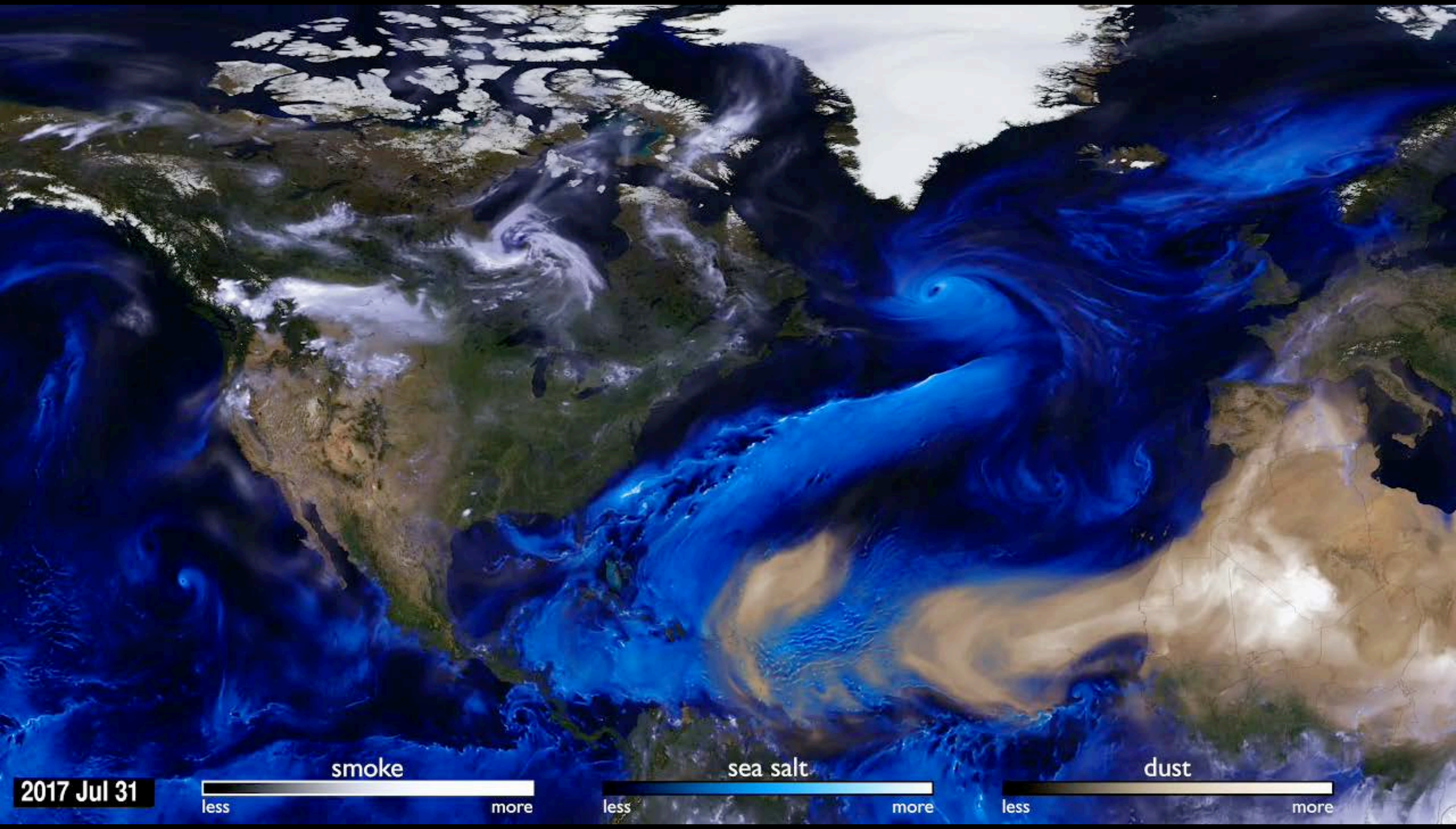
오늘의 내용

- 태풍


Typhoon Haiyan, November 2013


Typhoon Vongfong, October 2014

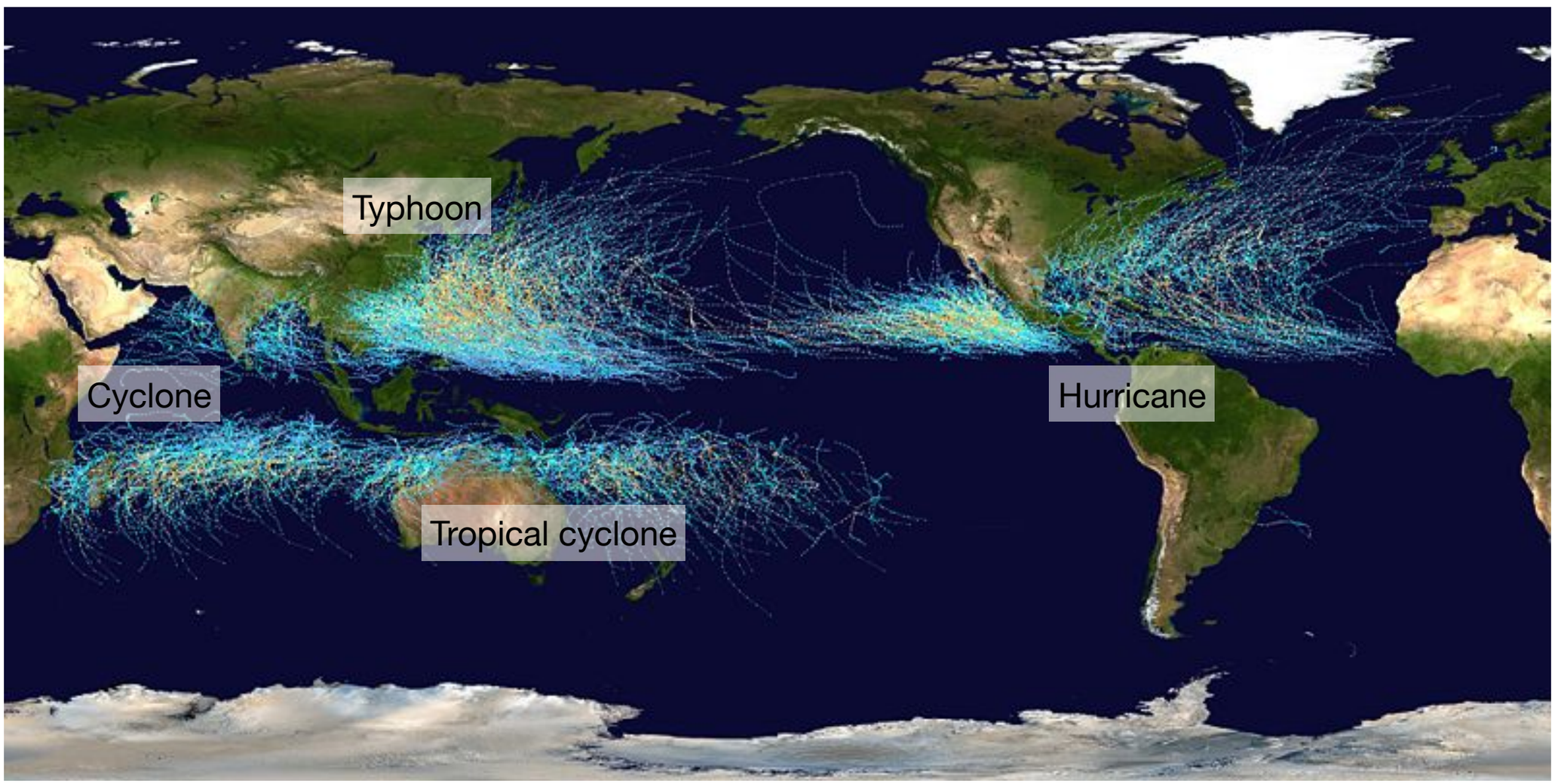
https://youtu.be/WjxZd7fPSVI



Movie from https://svs.gsfc.nasa.gov/12772

태풍, 허리케인, 사이클론

- 강력한 열대성 저기압
- 바람이 64 knots (74 mph, 119 km/h) 이상인 저기압

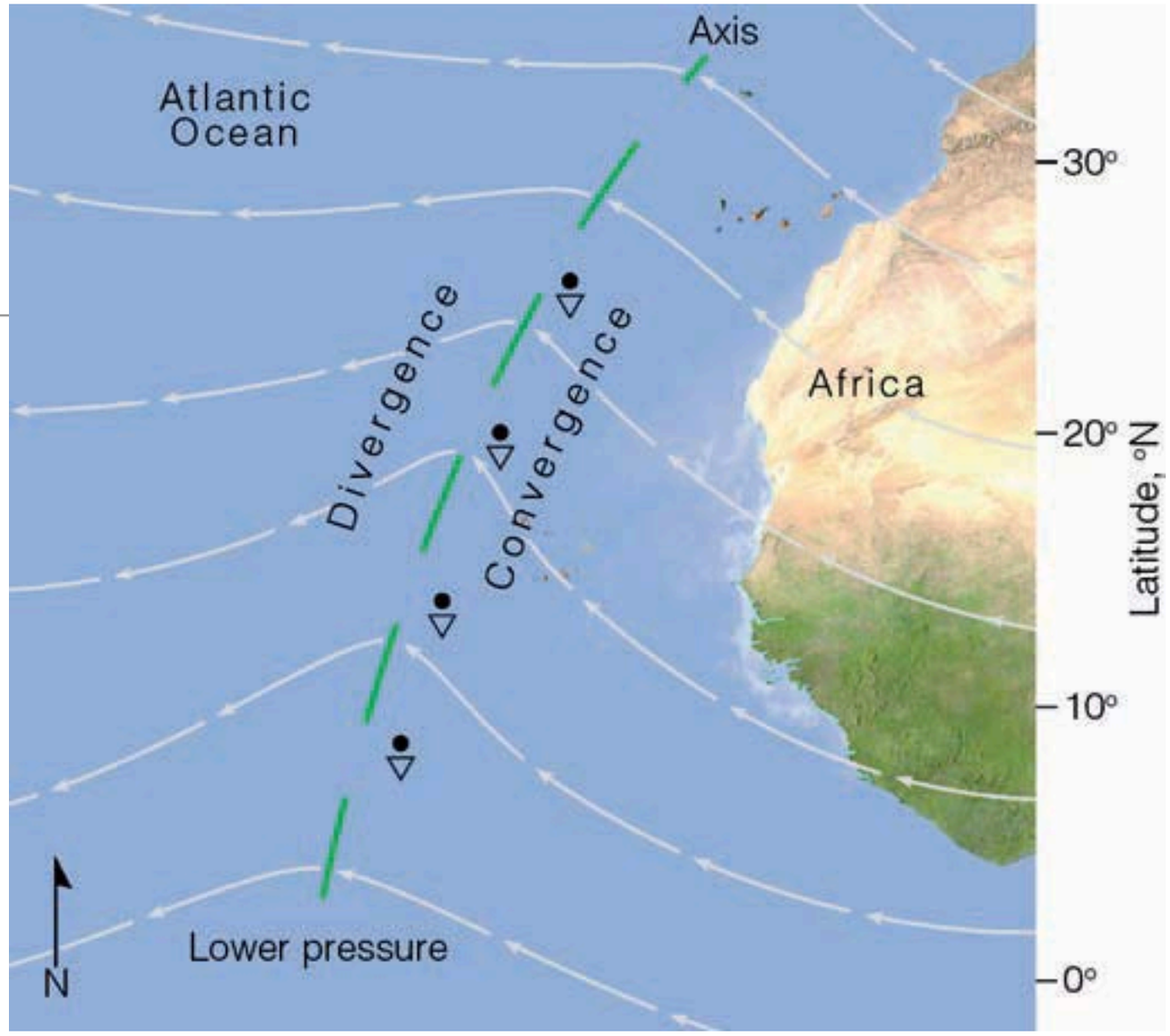


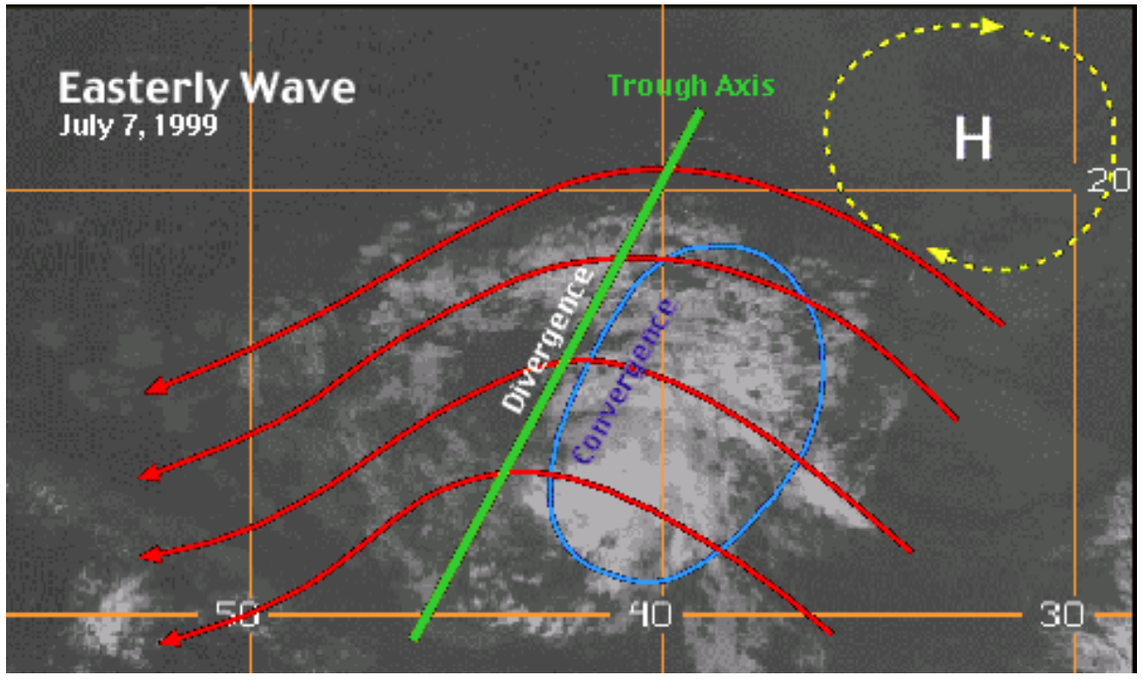
태풍의 생성

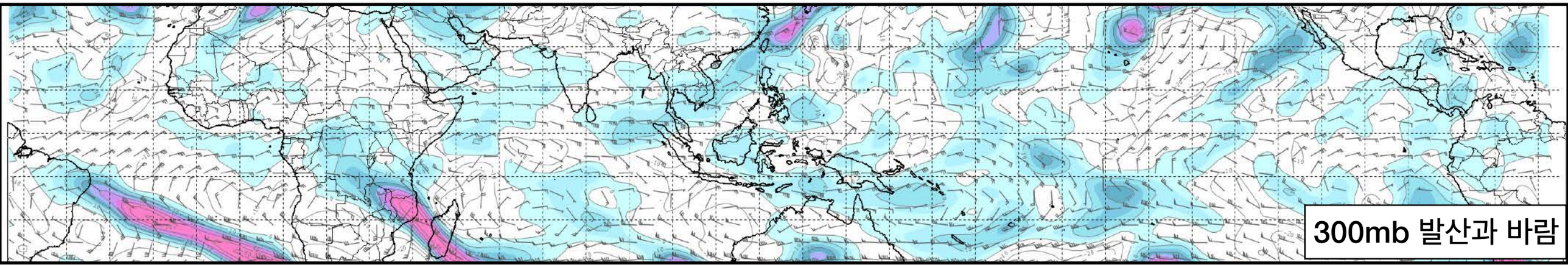
- 열대 지방에서는 강한 solar heating 으로 적운들이 발달하지만 대체로 독립적으로 존재함

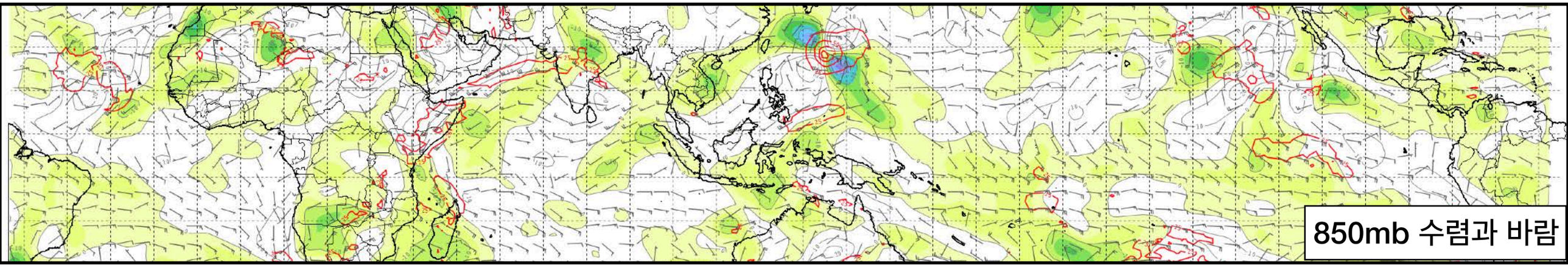
- 때때로 해수면 기압차이로 인한 편동풍파동이 발생

- 수렴 지역의 상승으로 적운들이 커다란 태풍으로 발달할 수 있음









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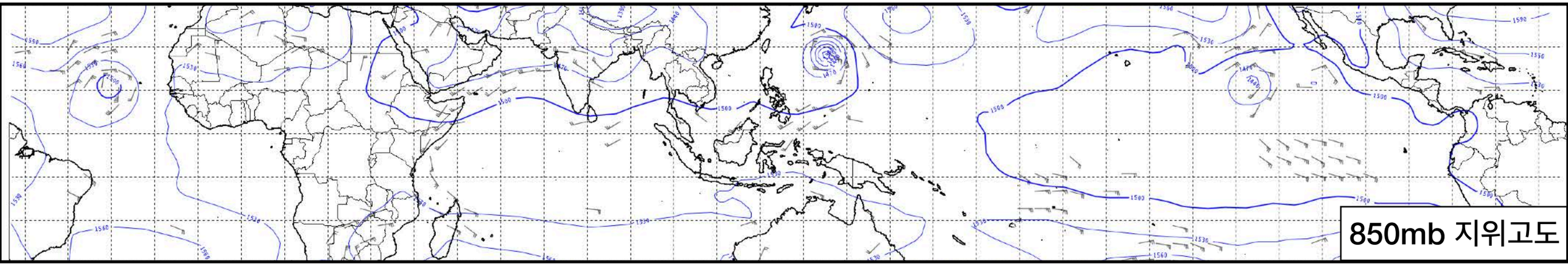

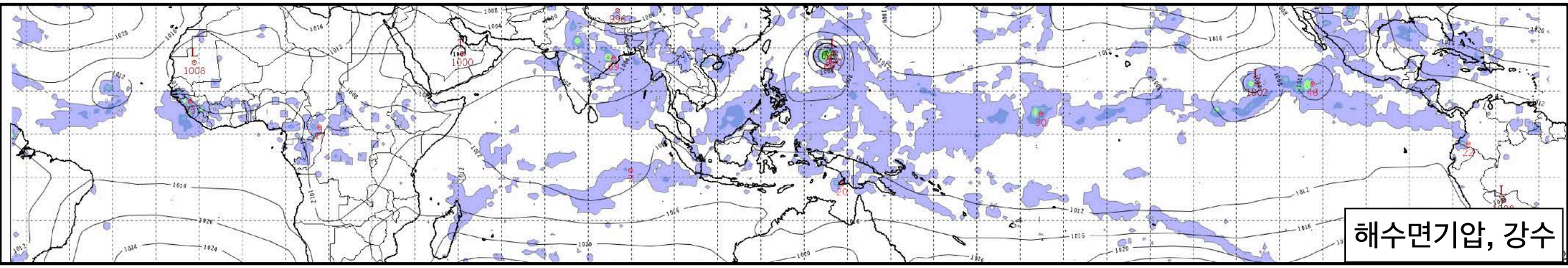

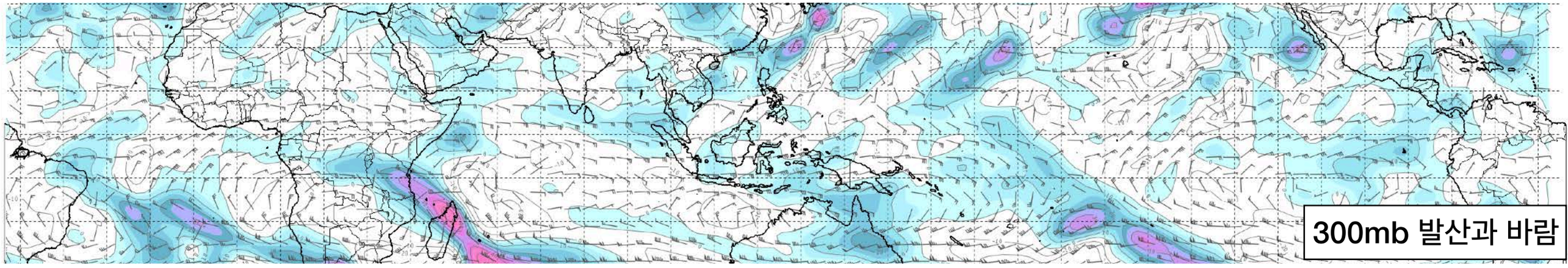

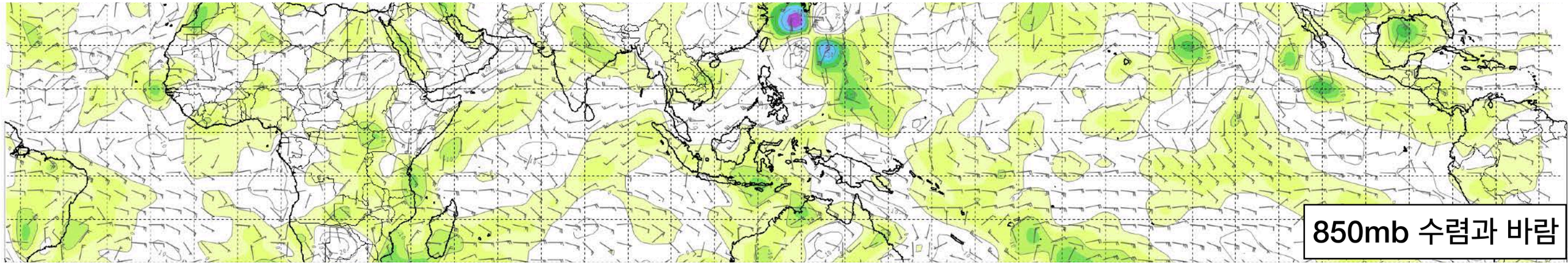

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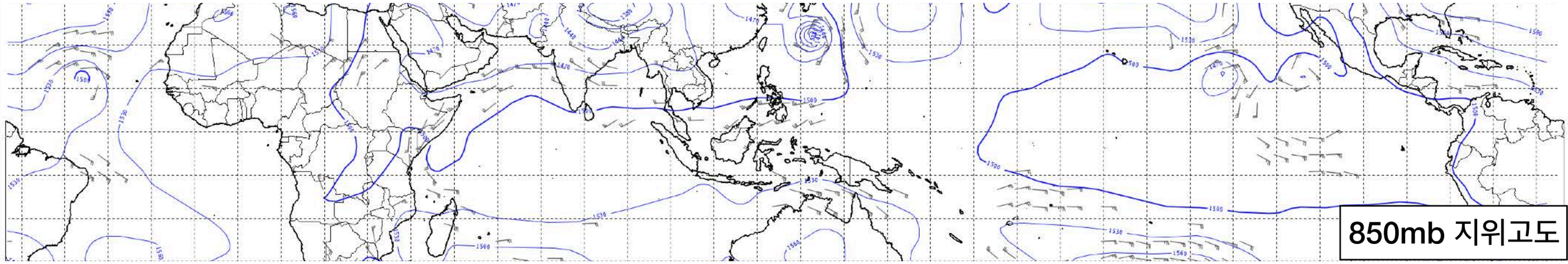

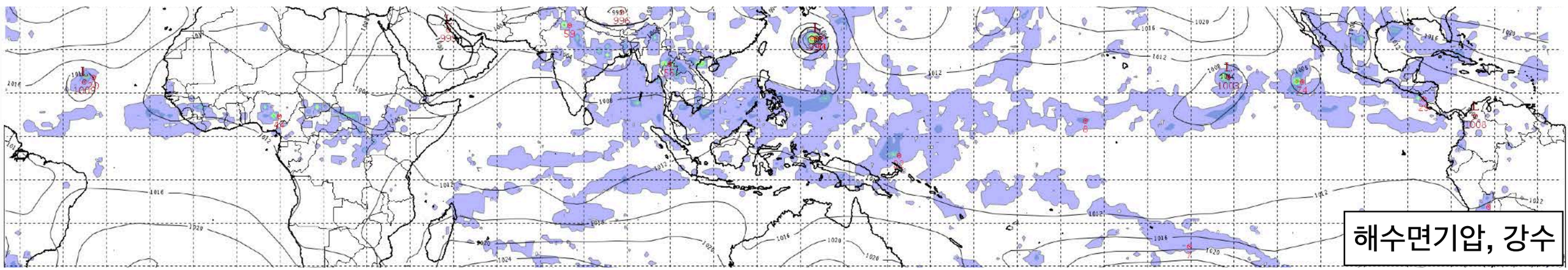

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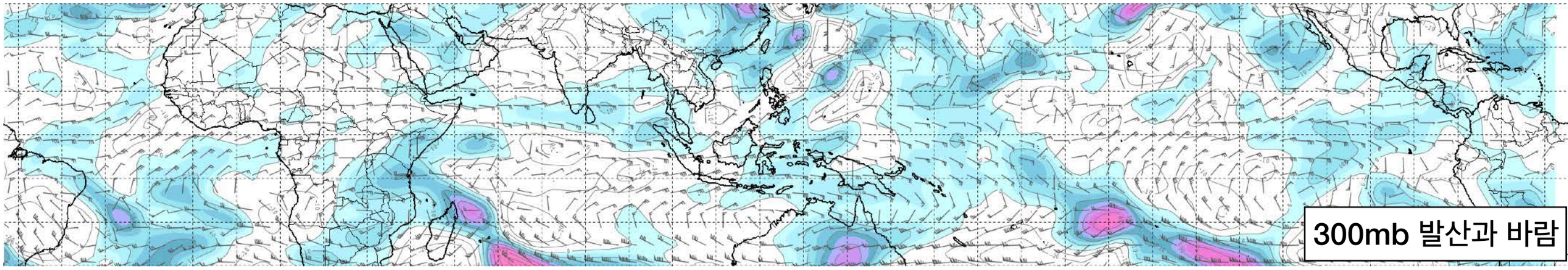

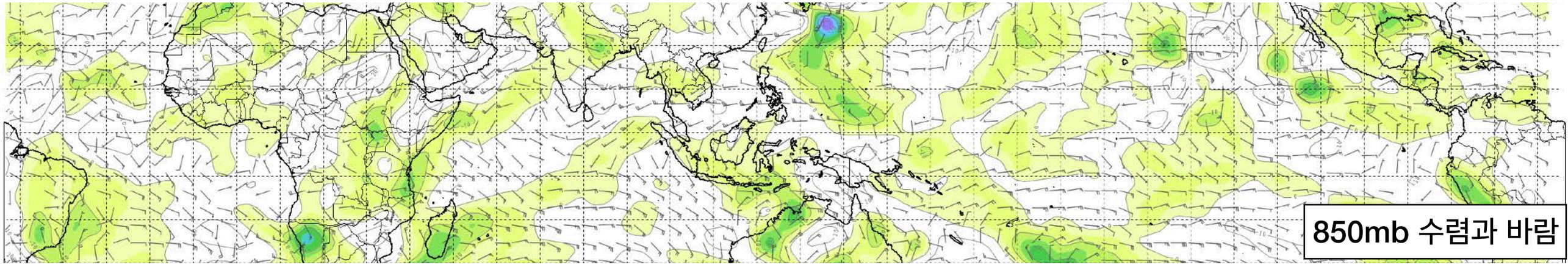

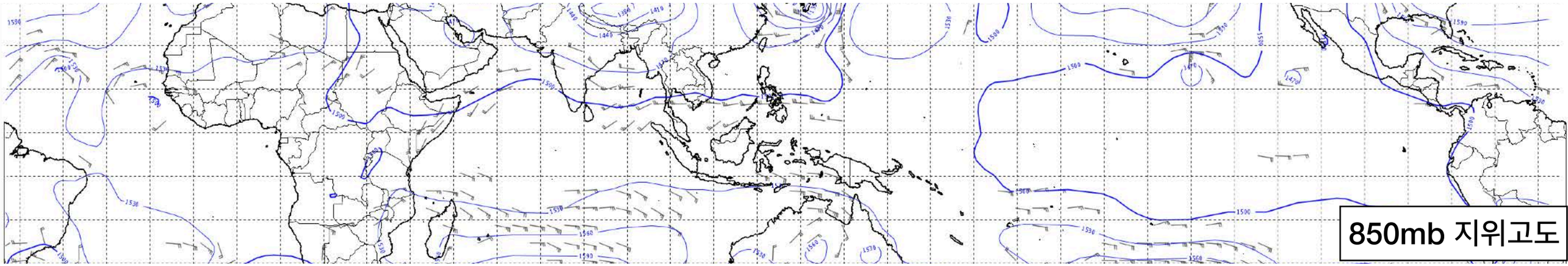

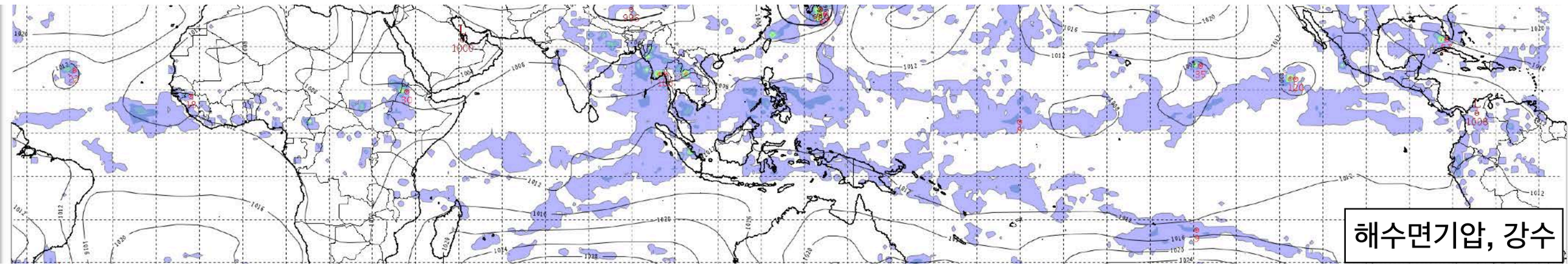

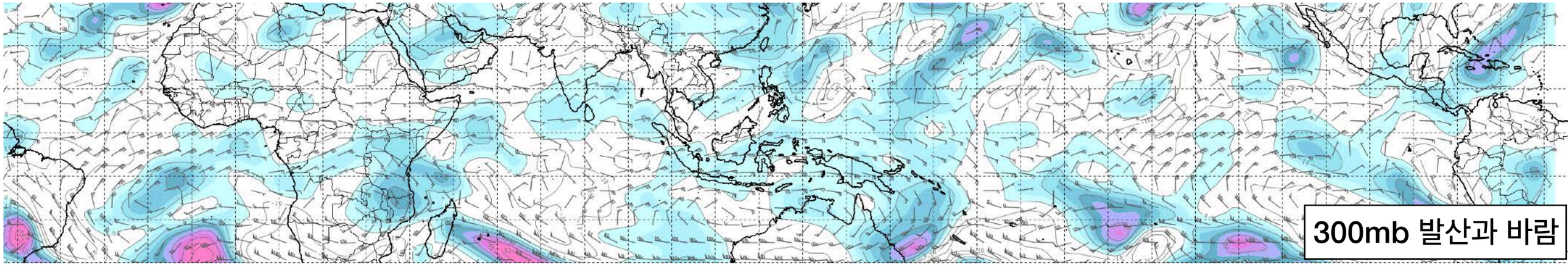

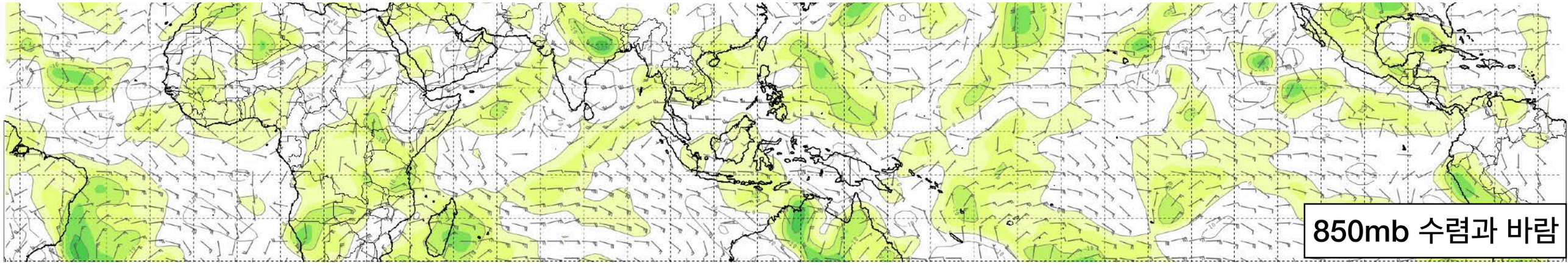

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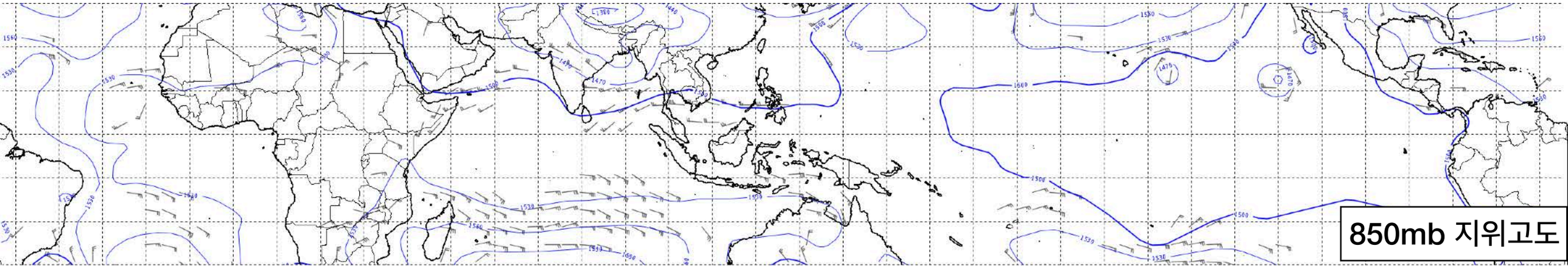

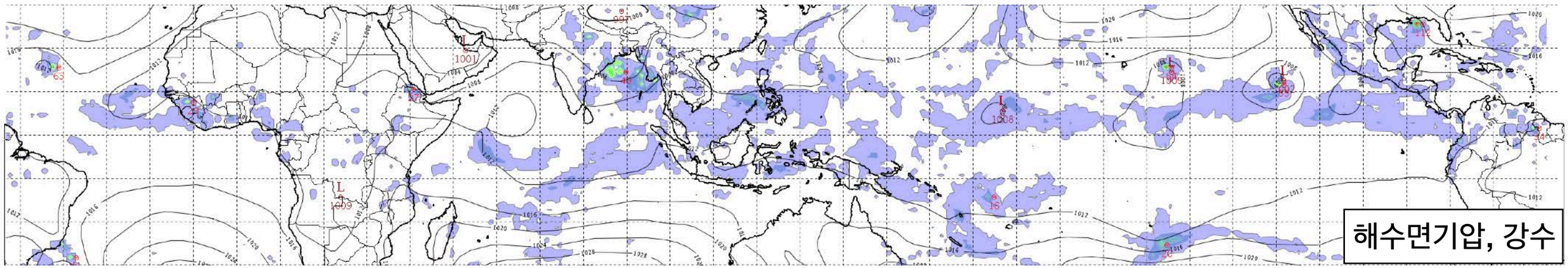

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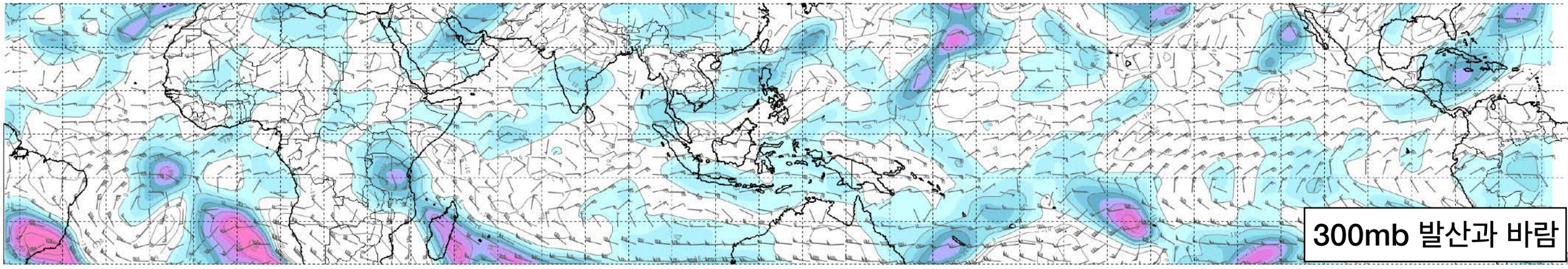

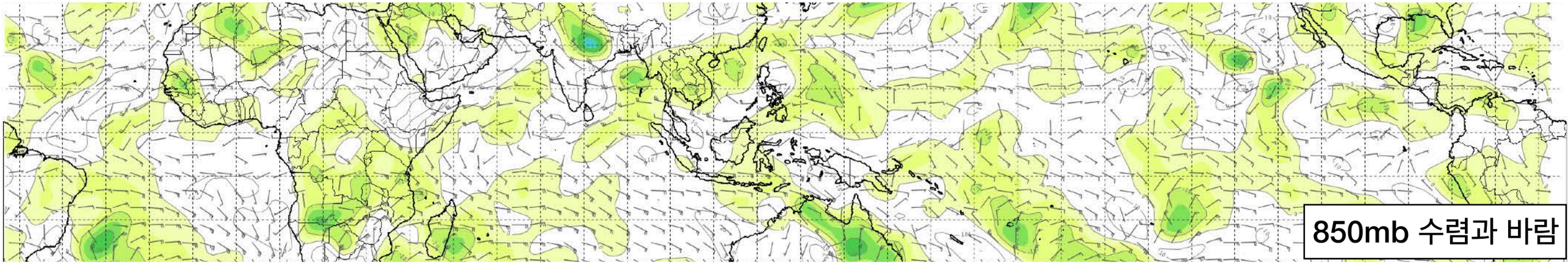

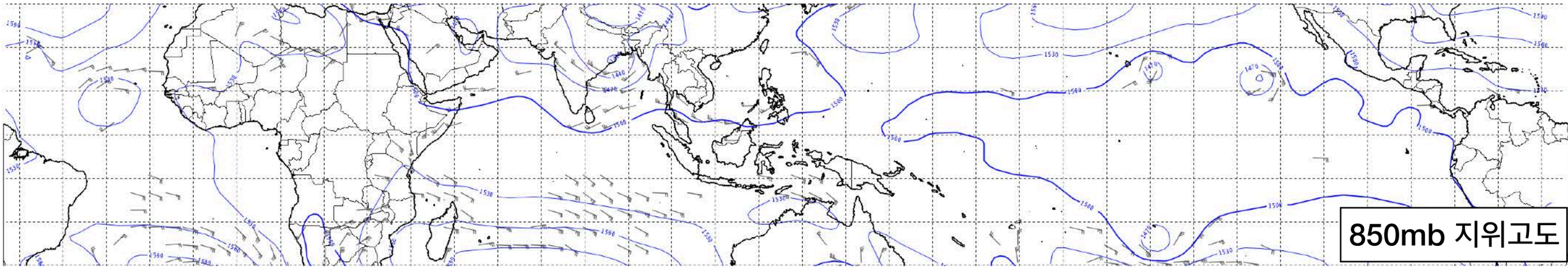

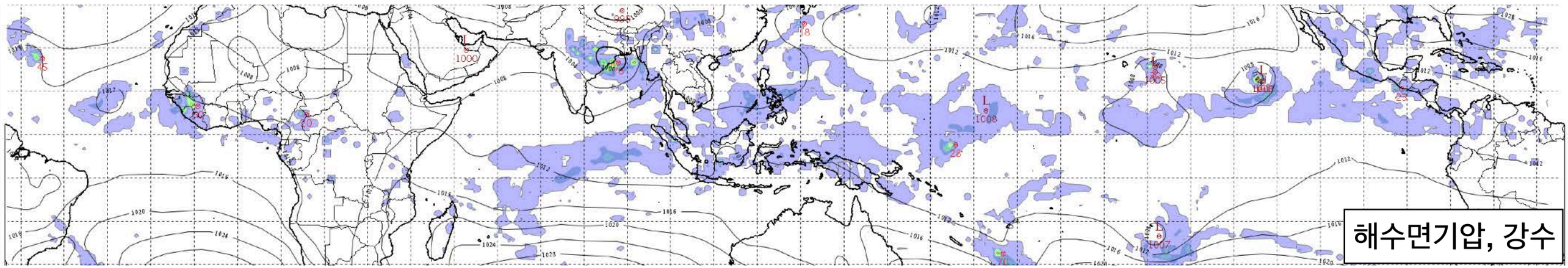

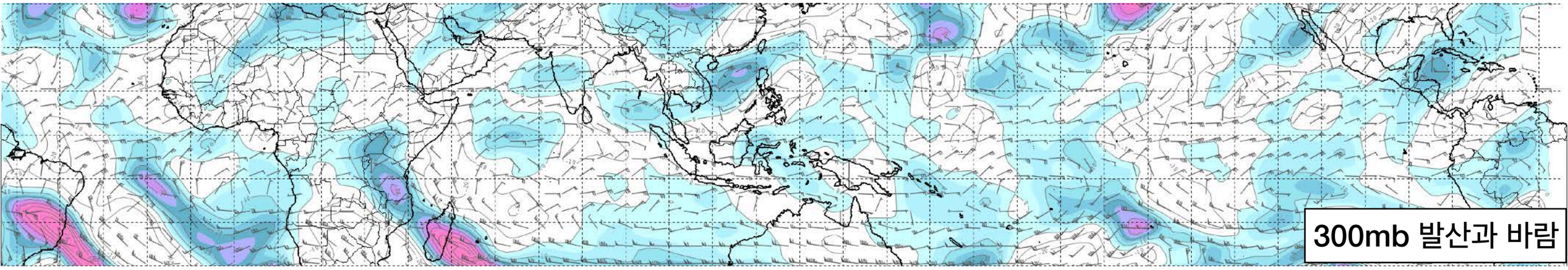

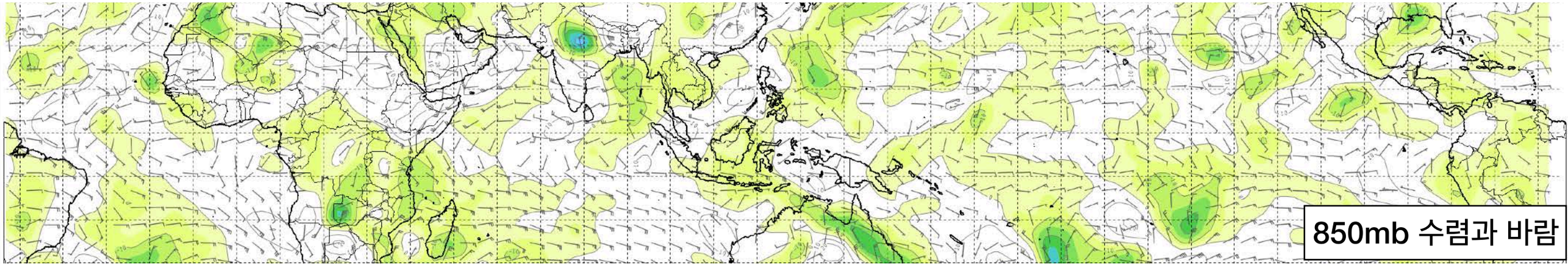

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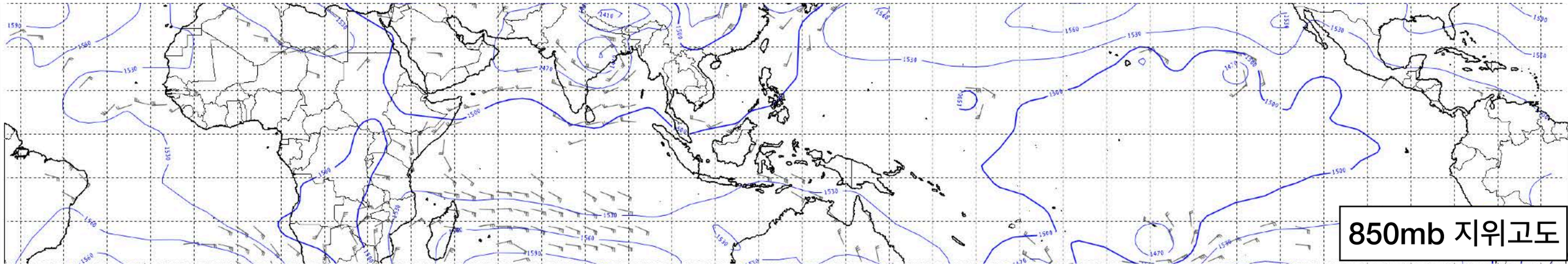

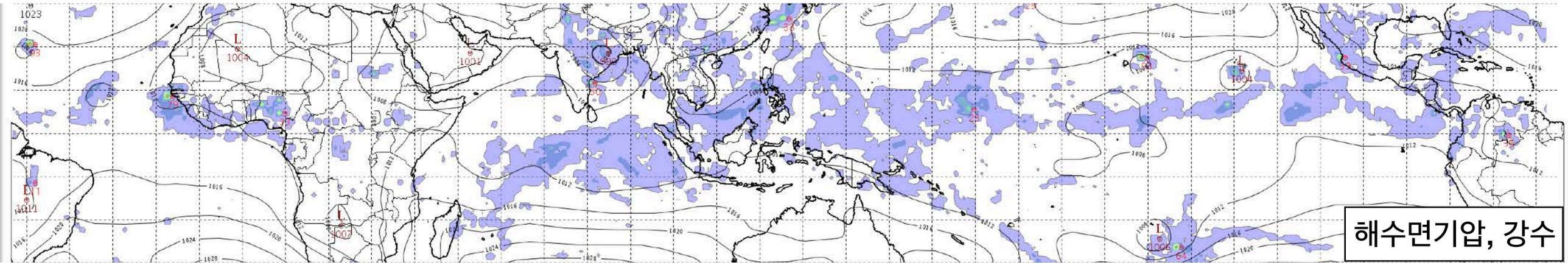

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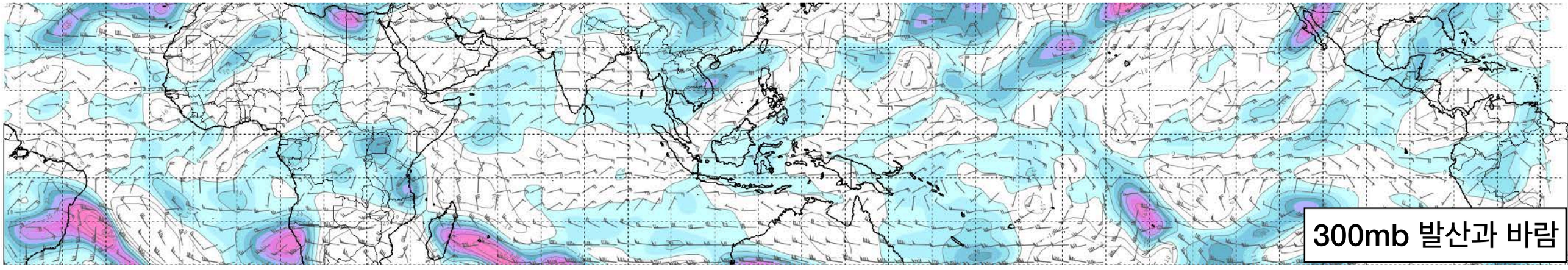

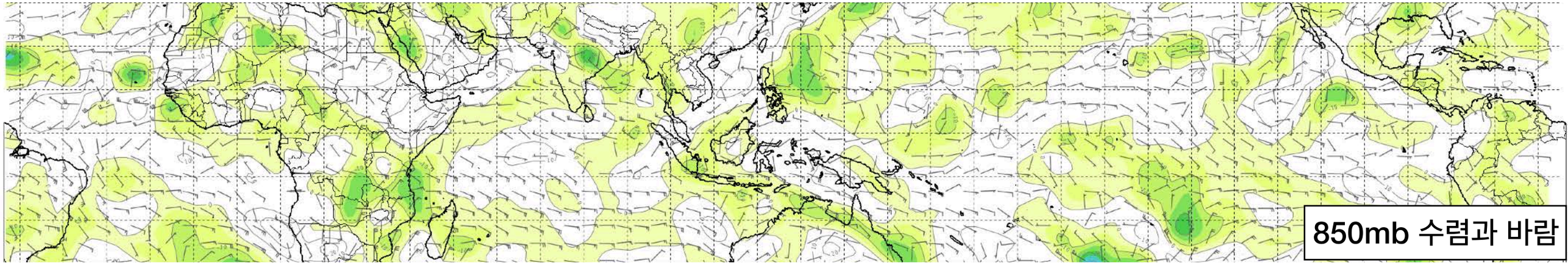

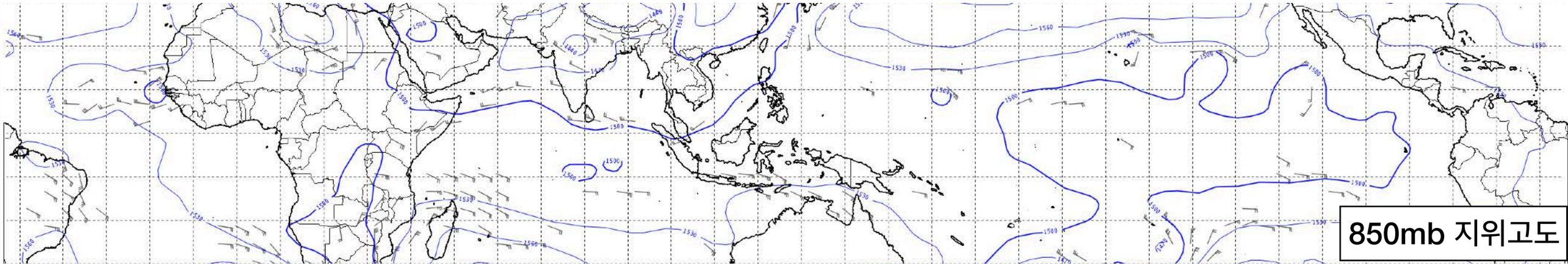

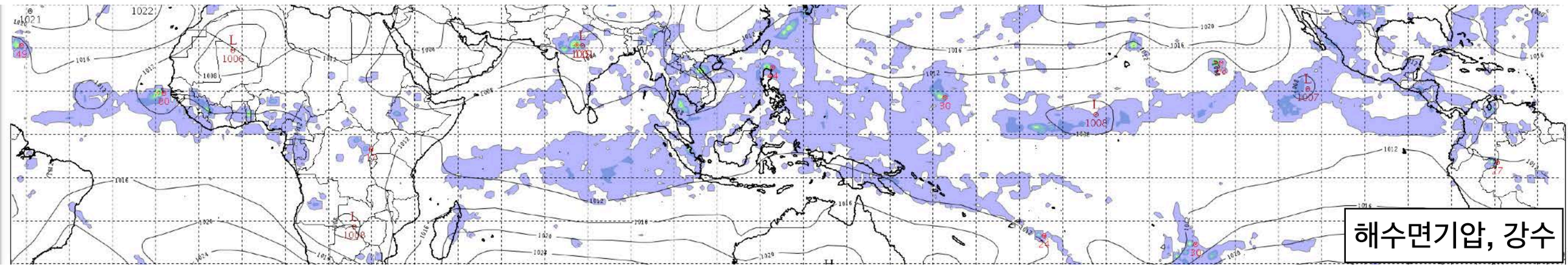

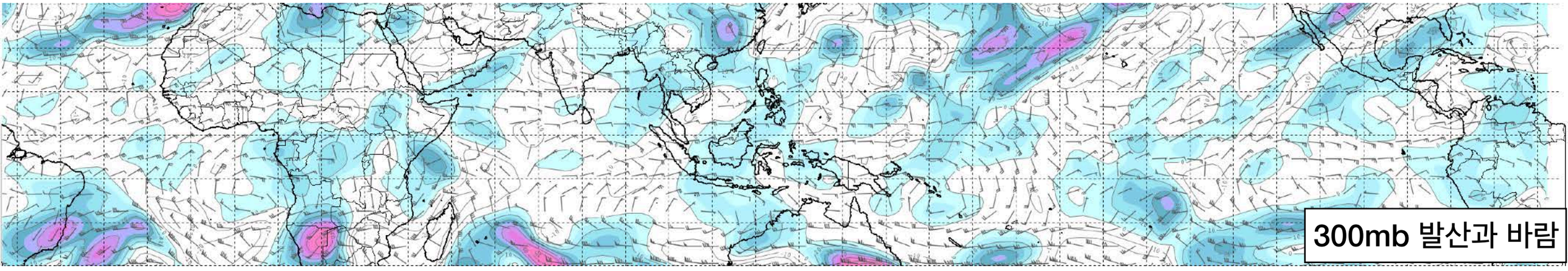

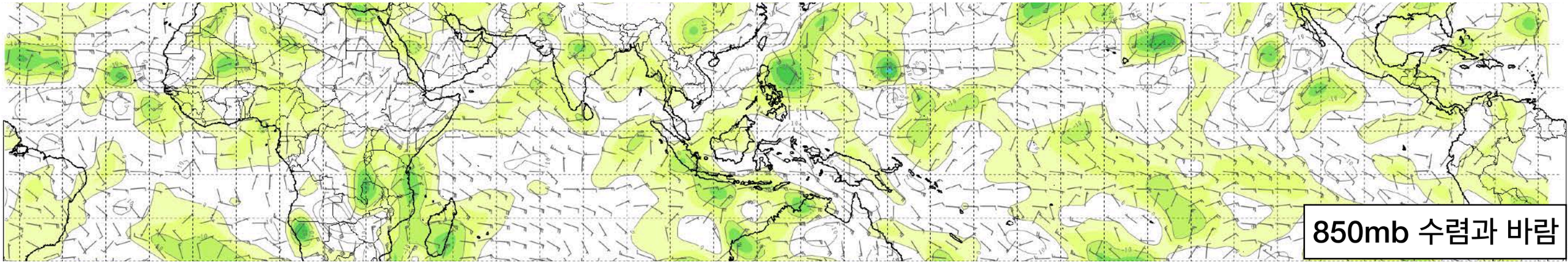

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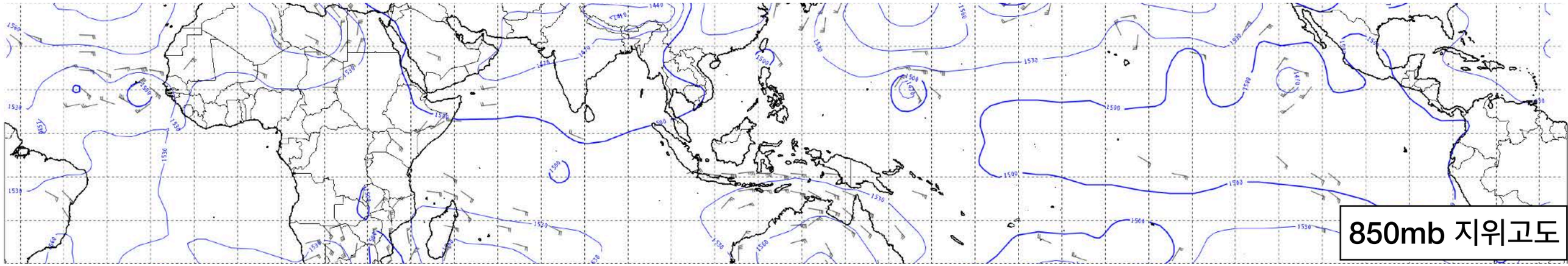

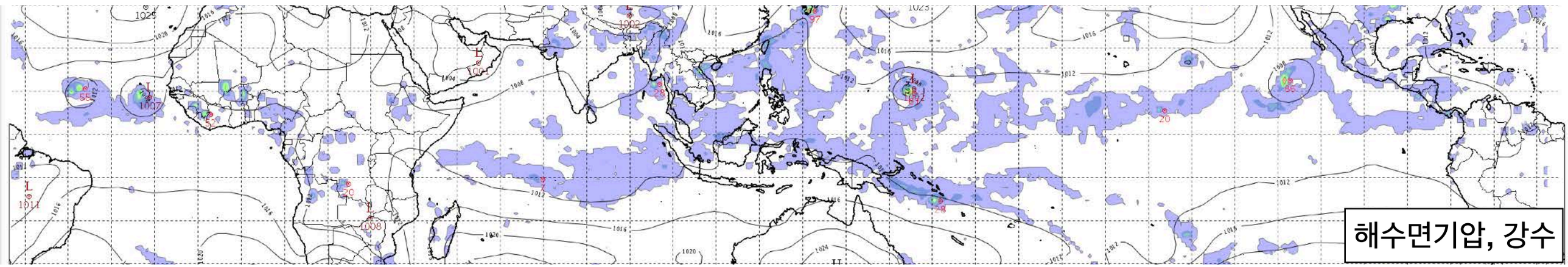

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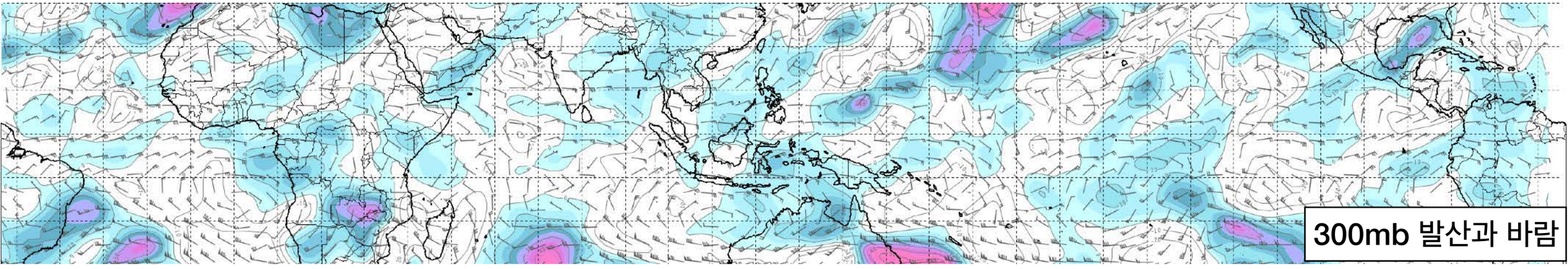

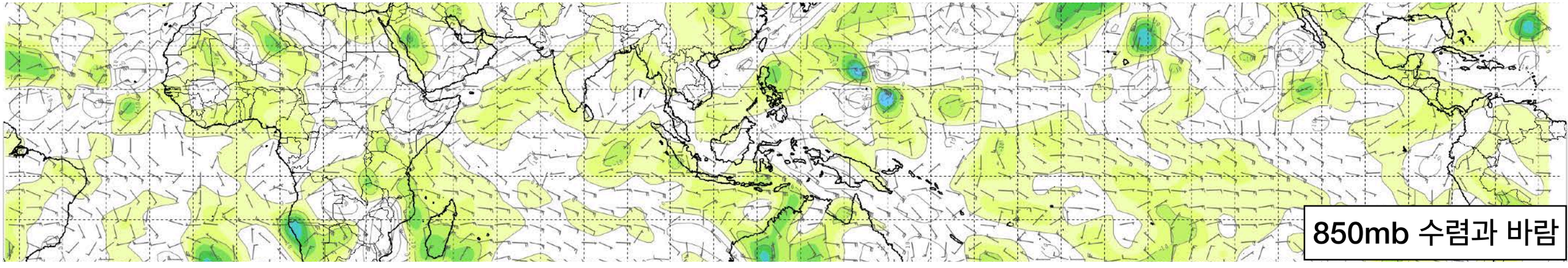

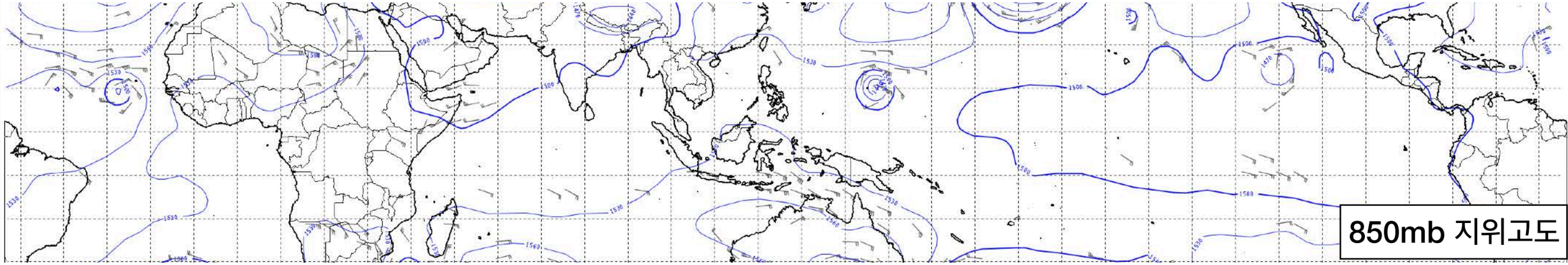

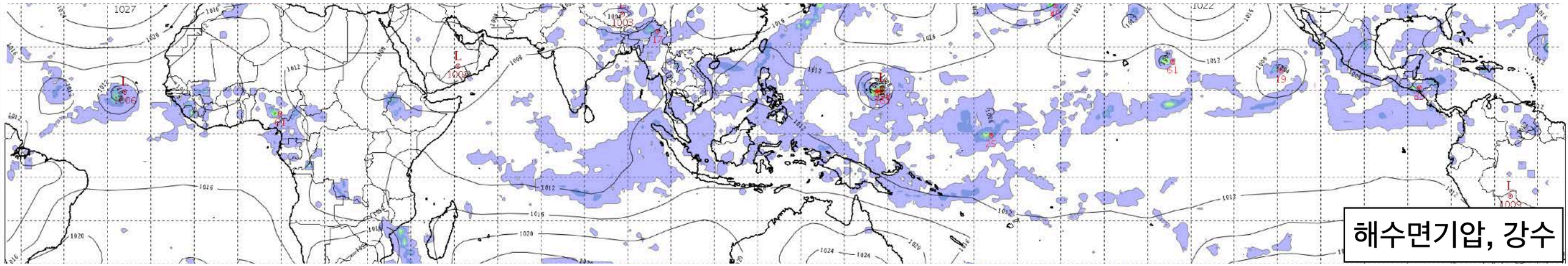

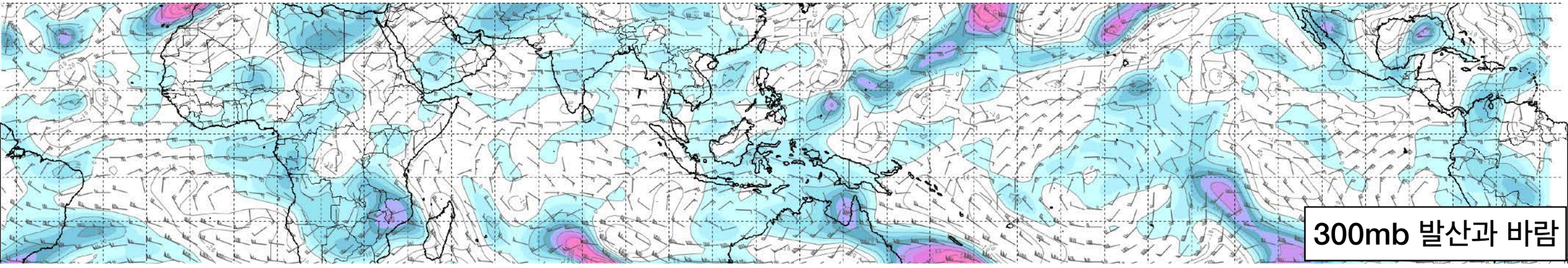

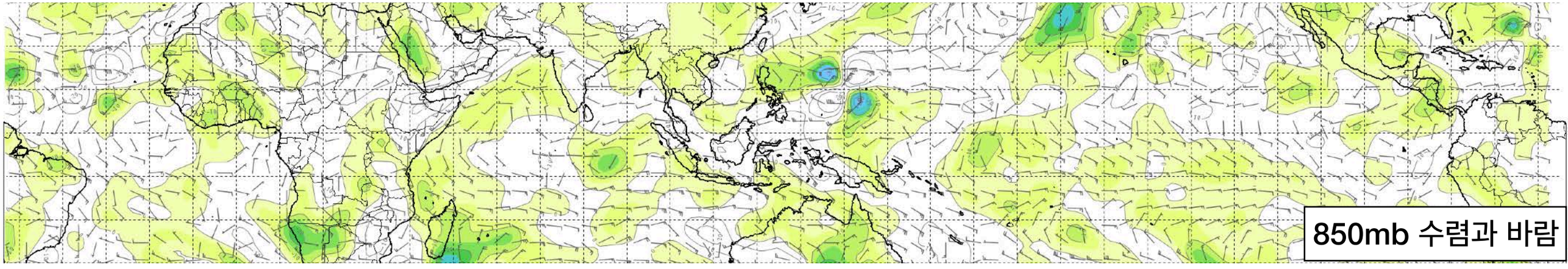

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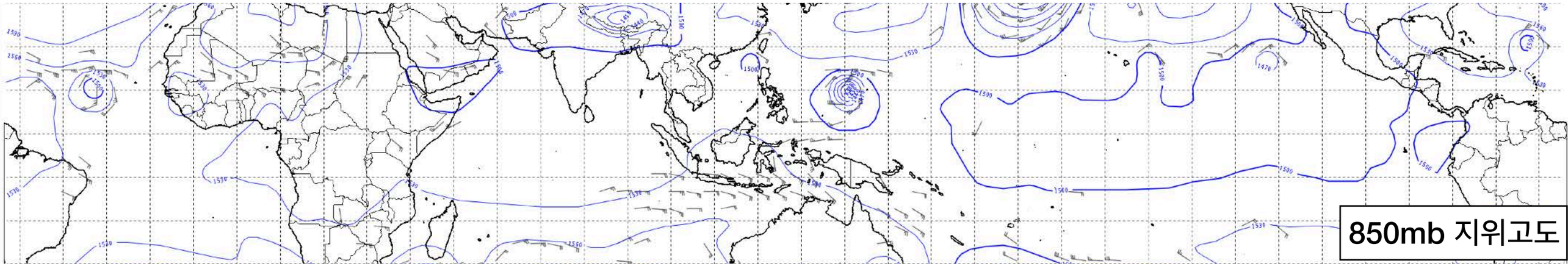

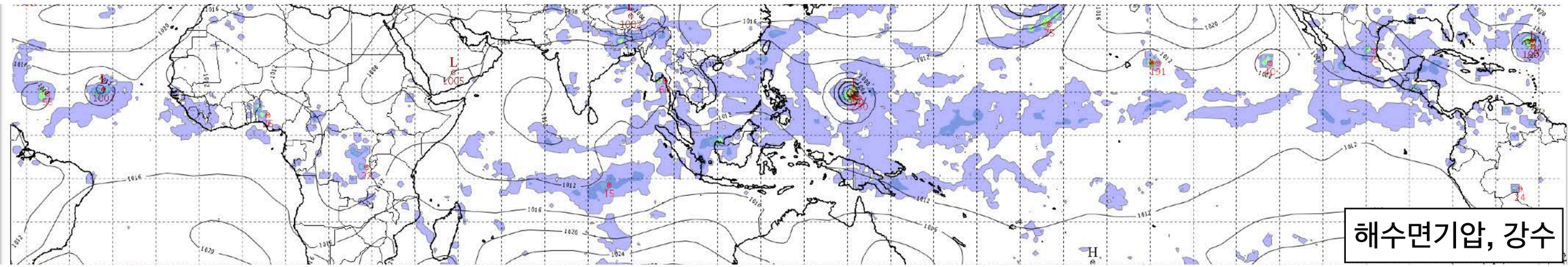

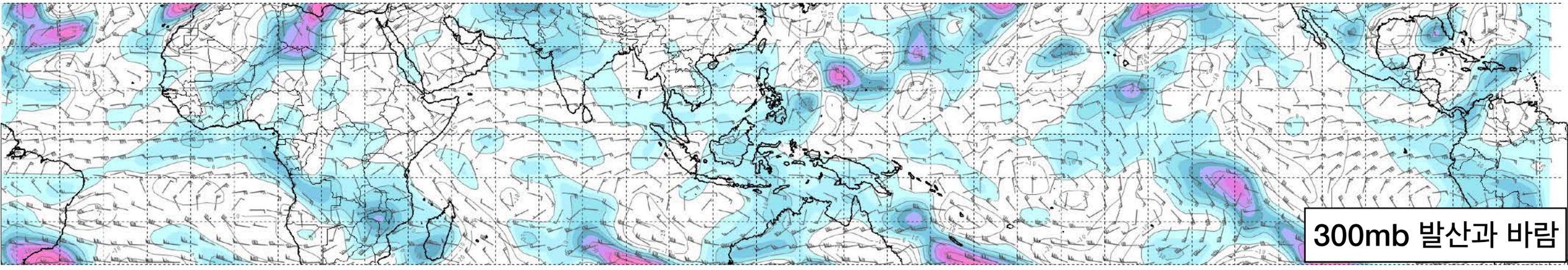

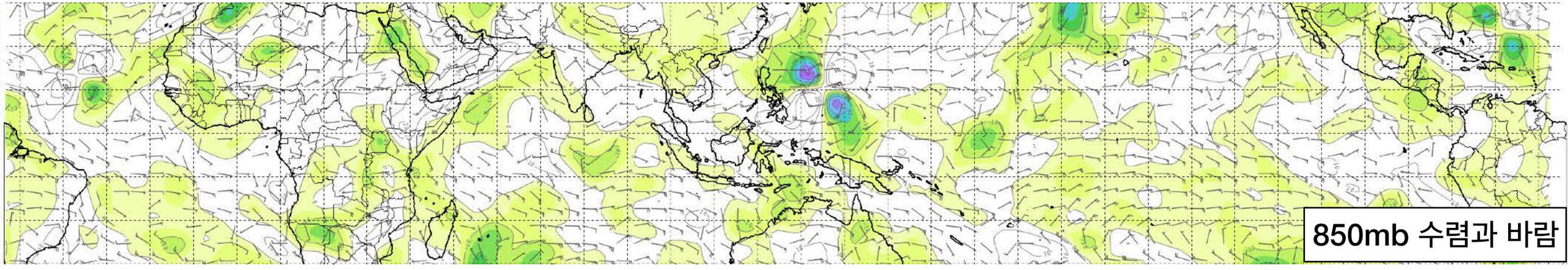

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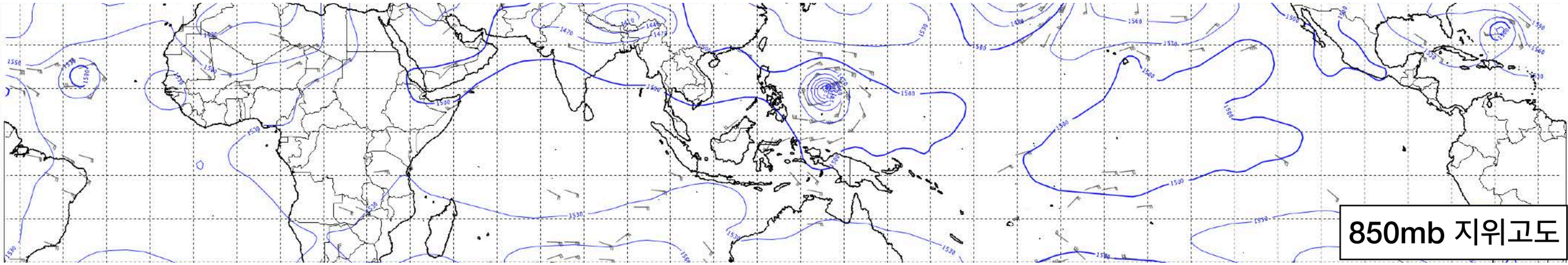

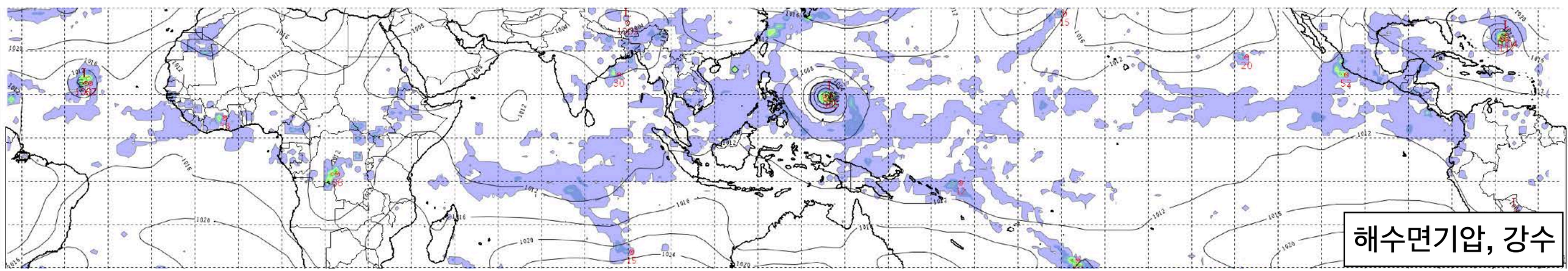

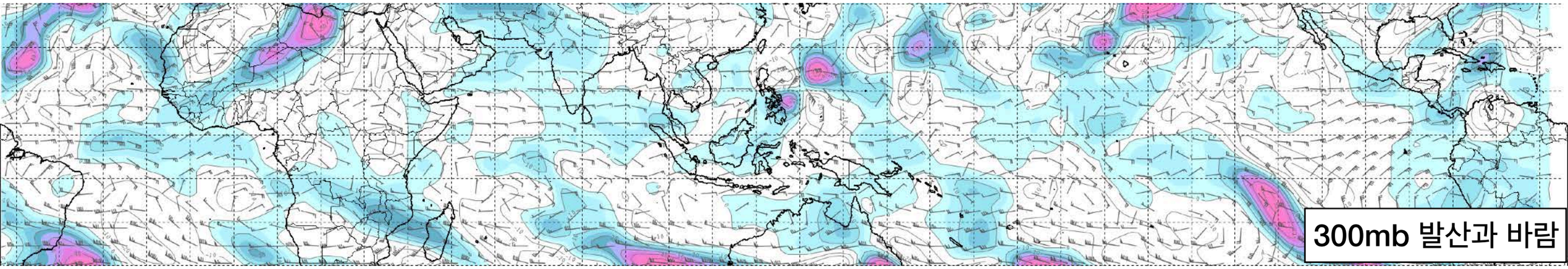

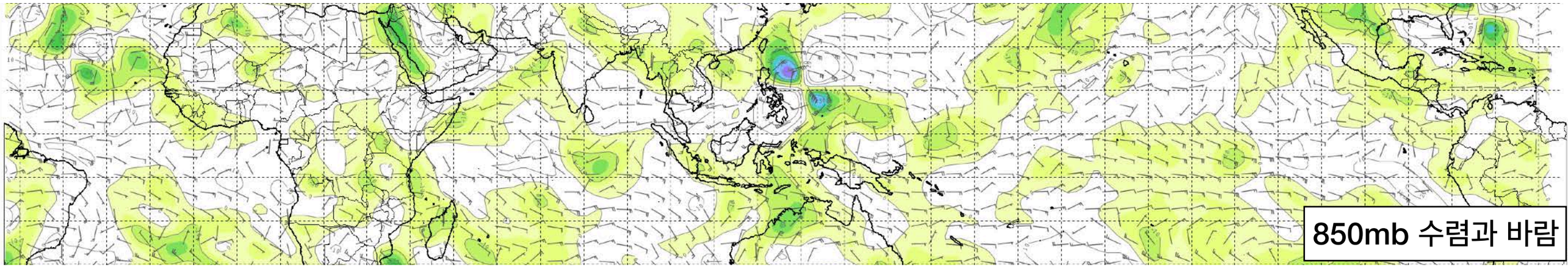

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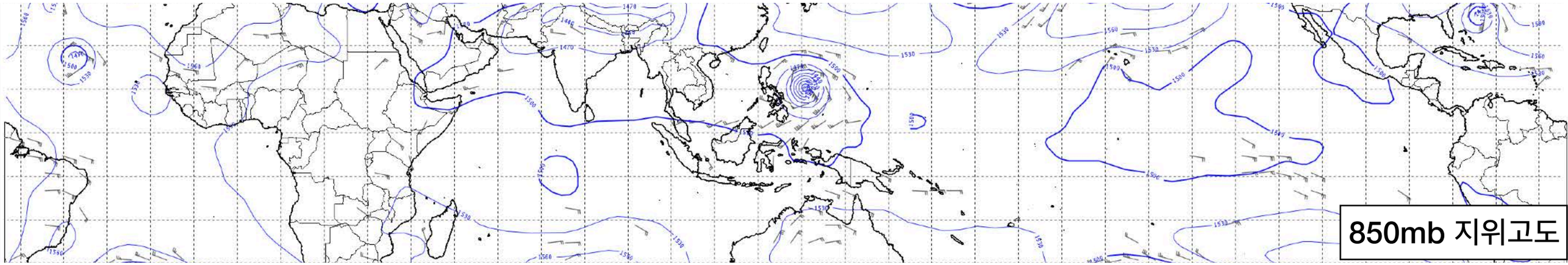

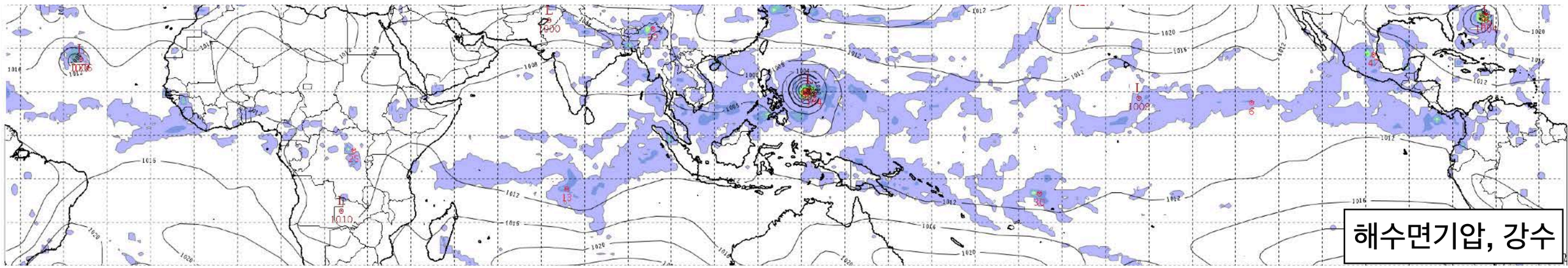

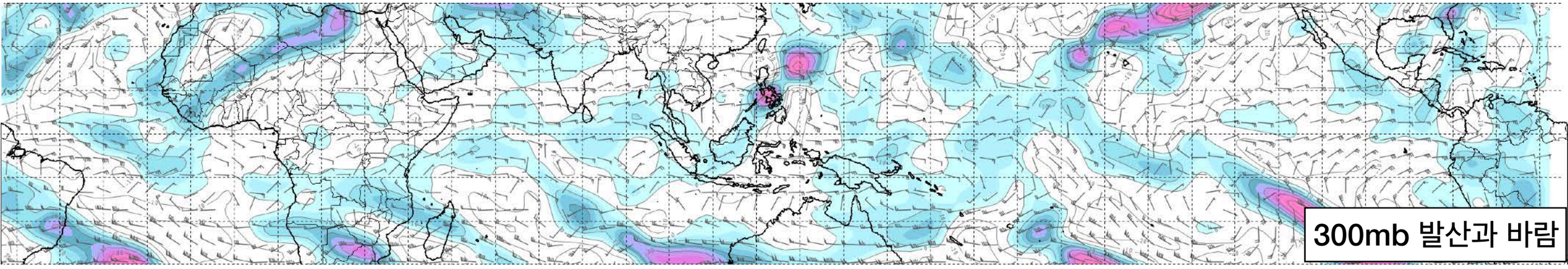

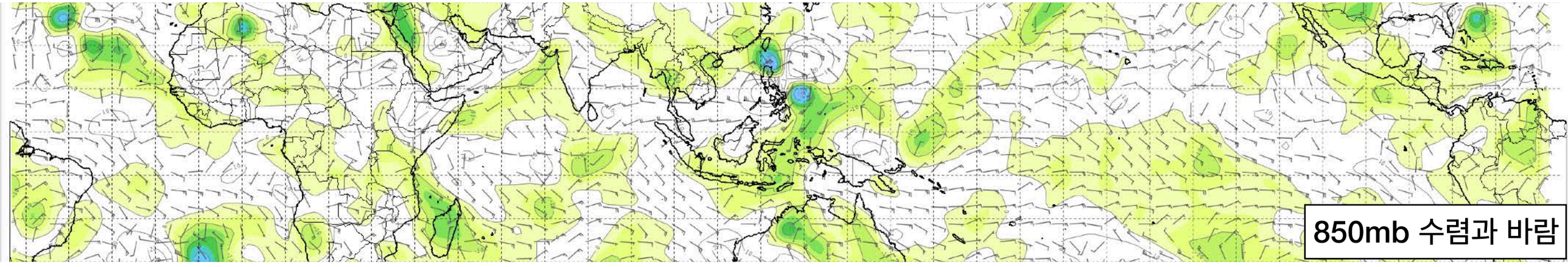

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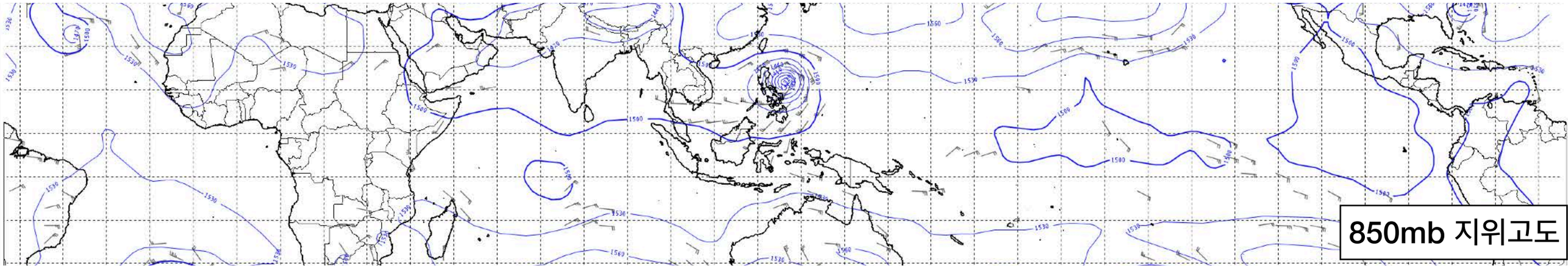

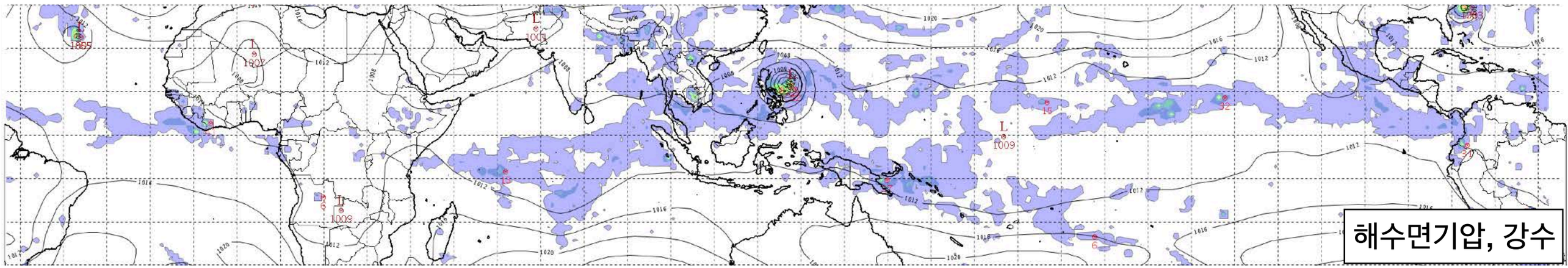

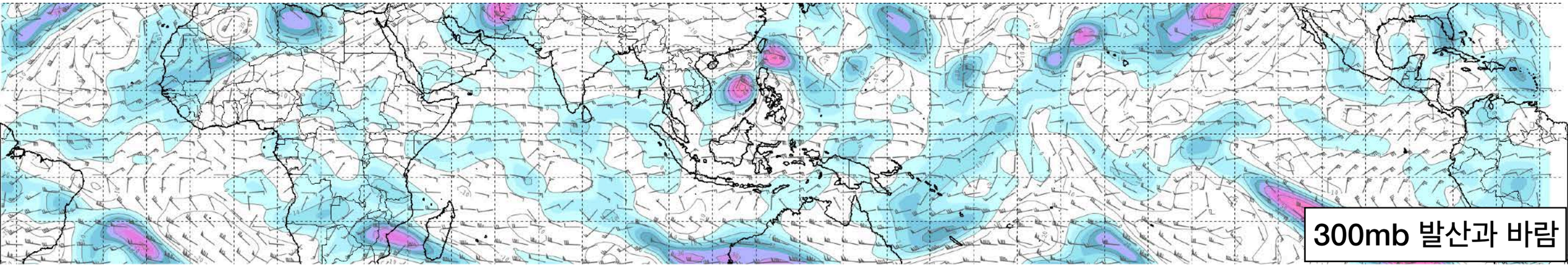

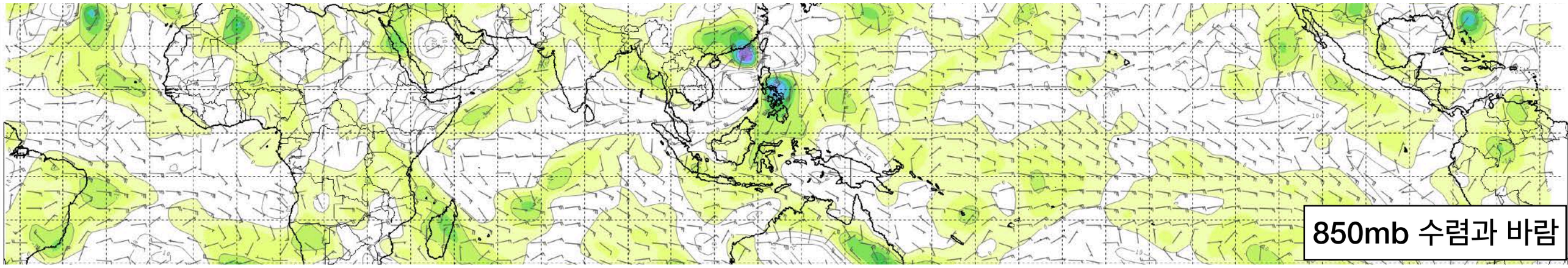

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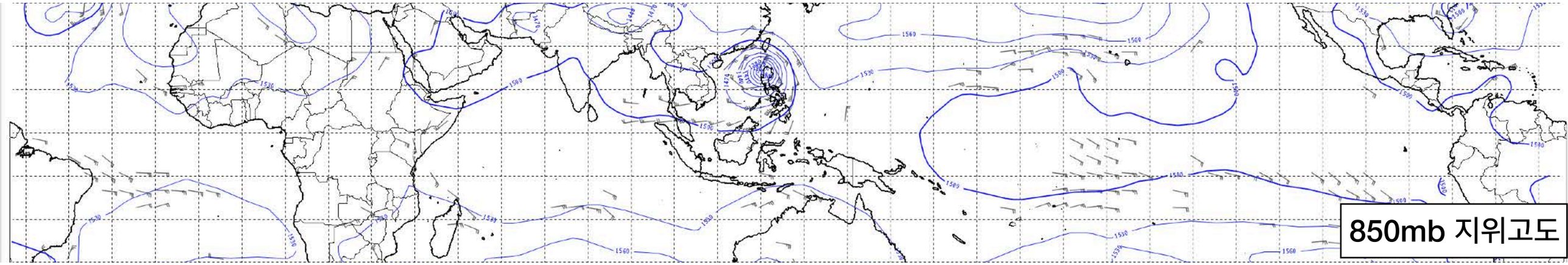

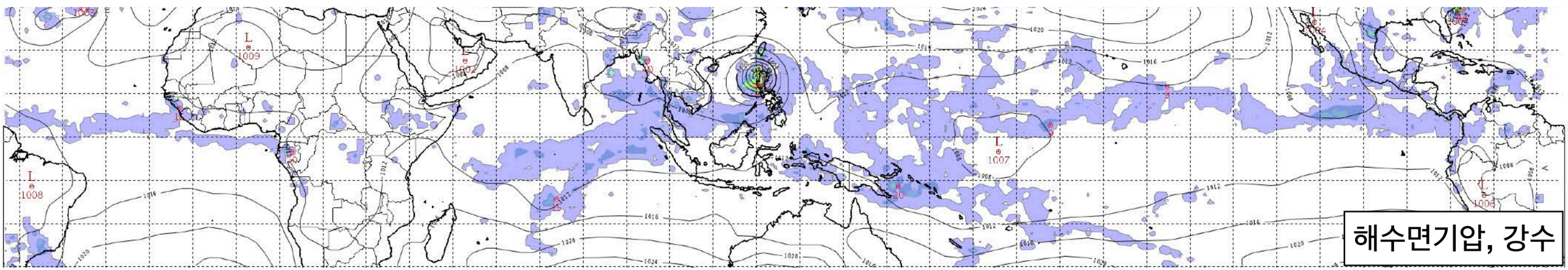

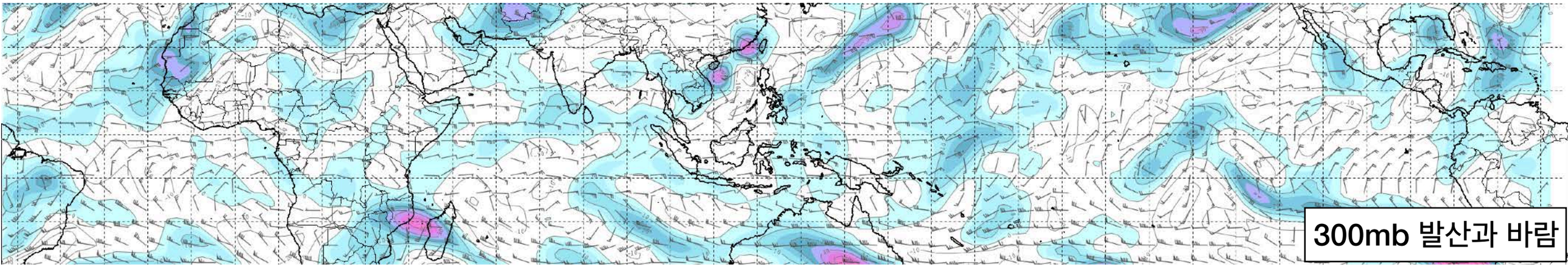

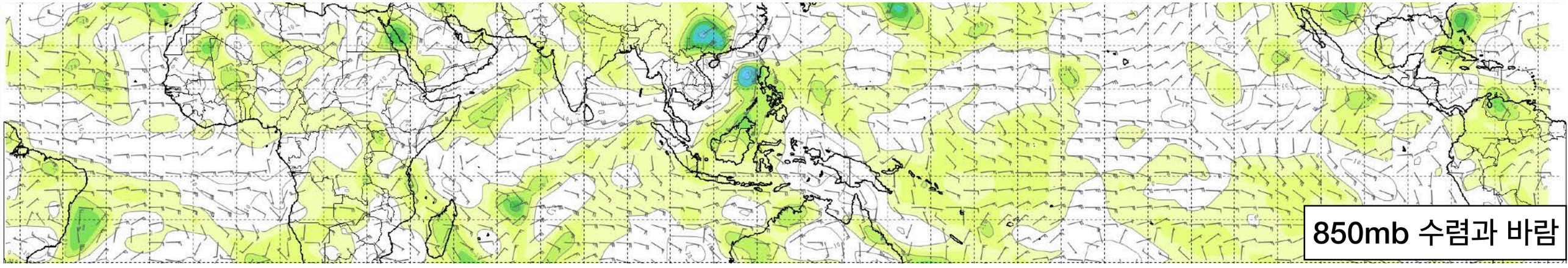

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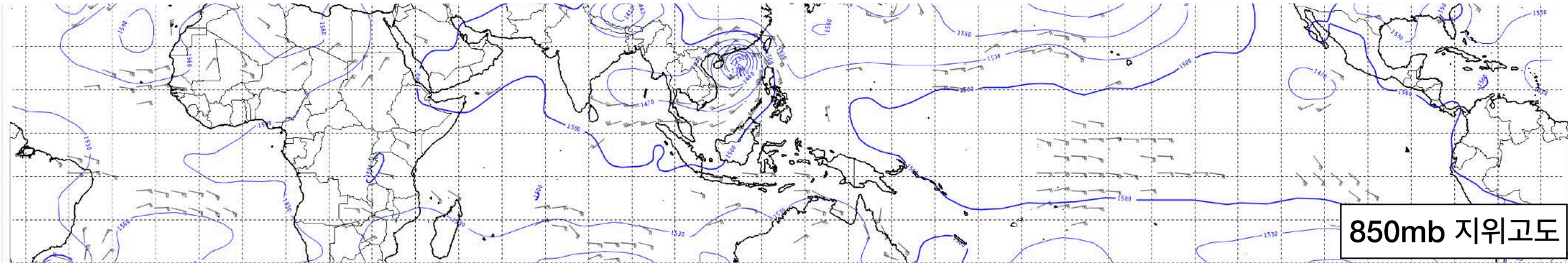

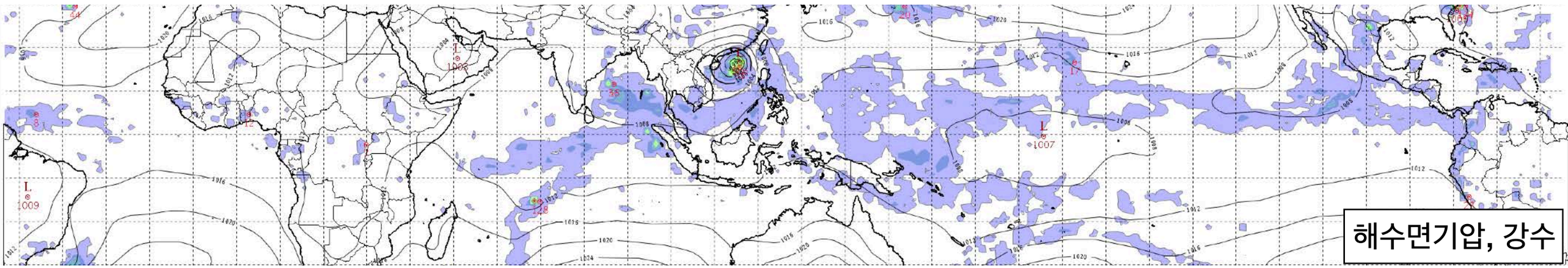

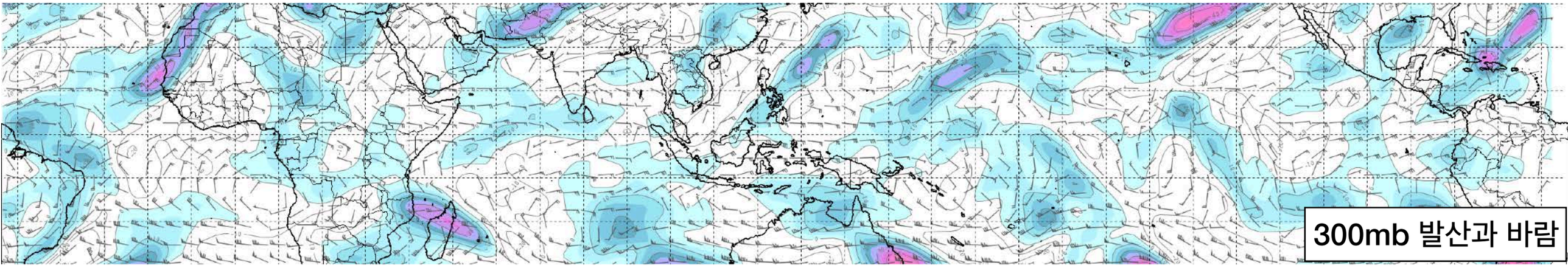

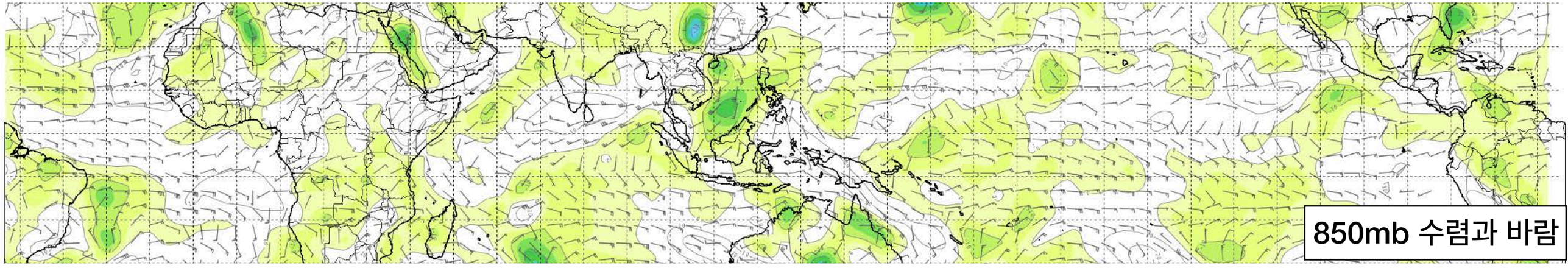

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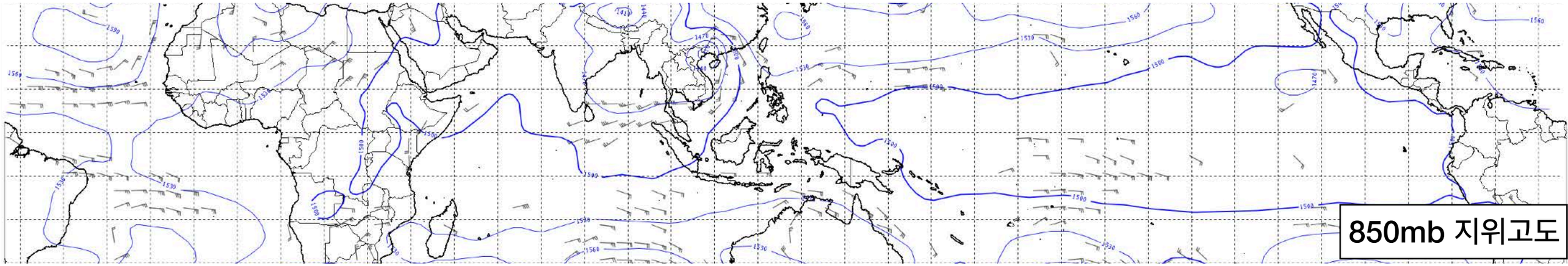
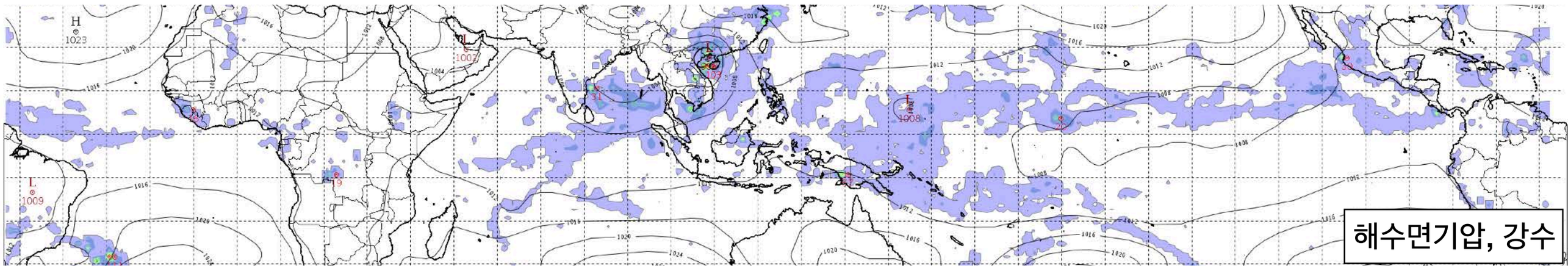
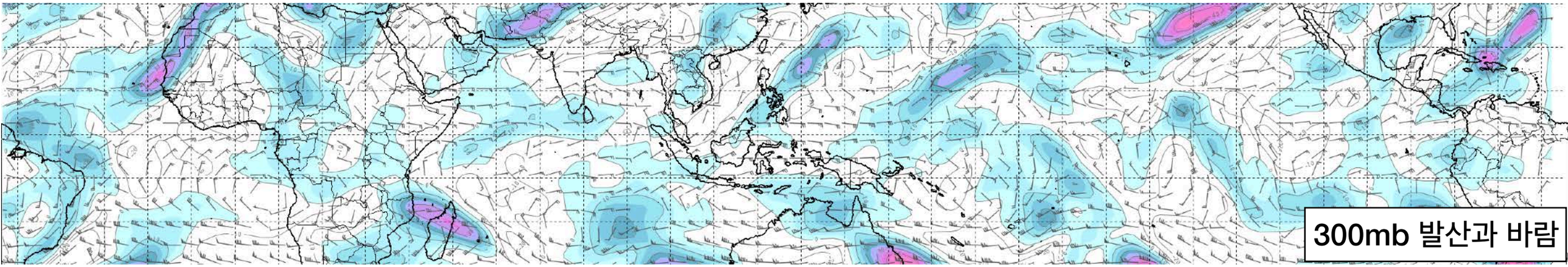
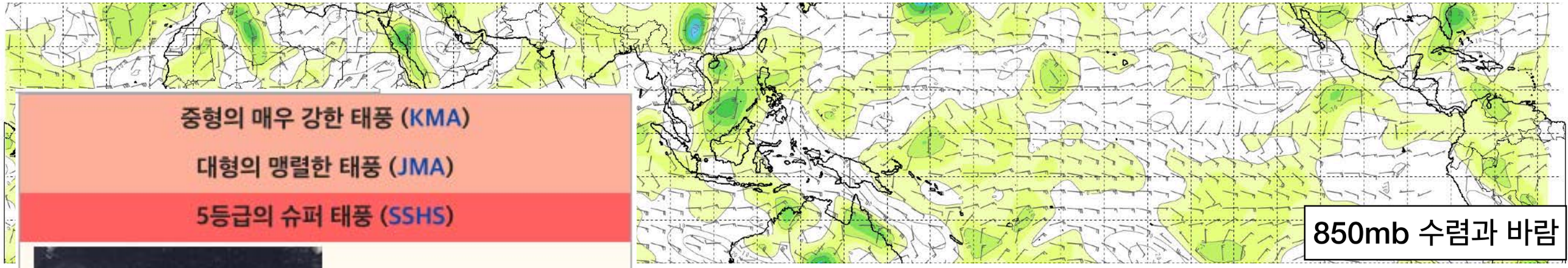




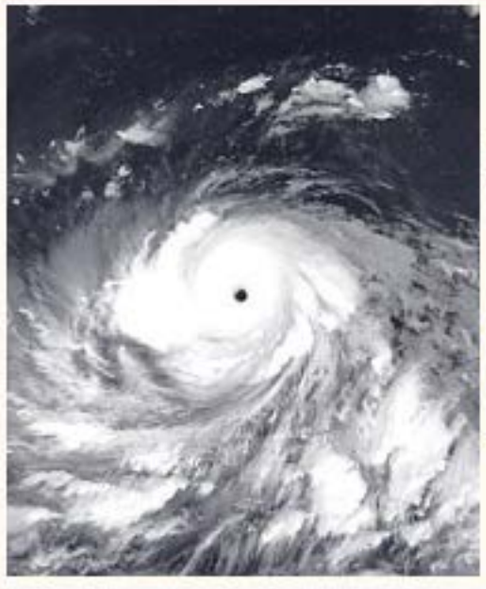


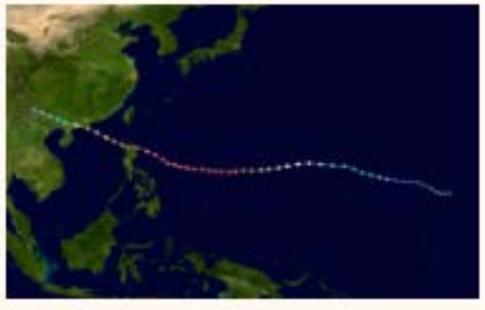


중형의 매우 강한 태풍 (KMA)

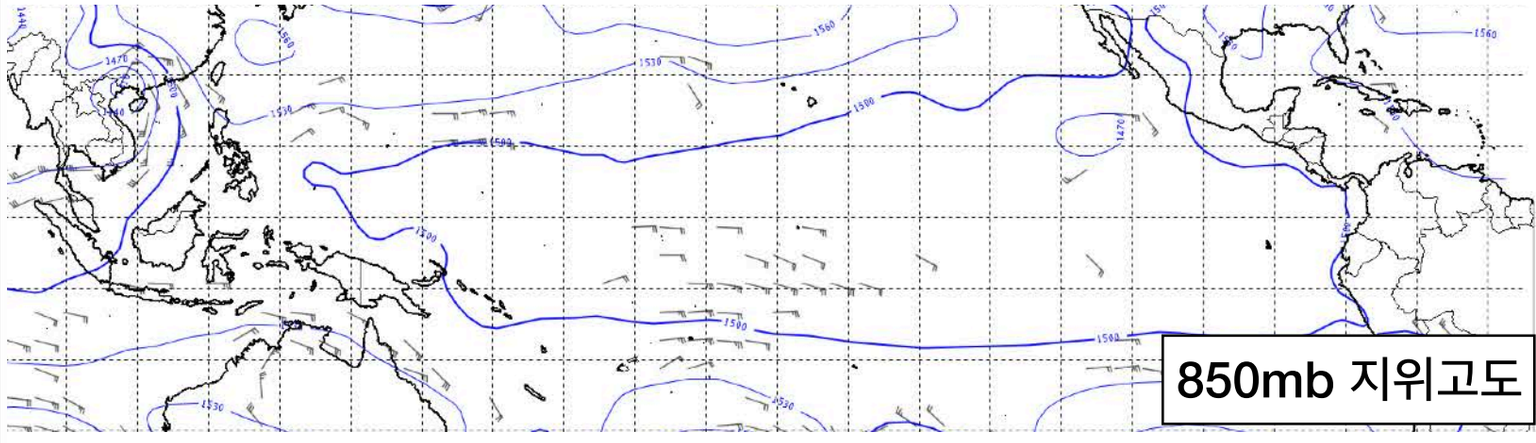
대형의 맹렬한 태풍 (JMA)

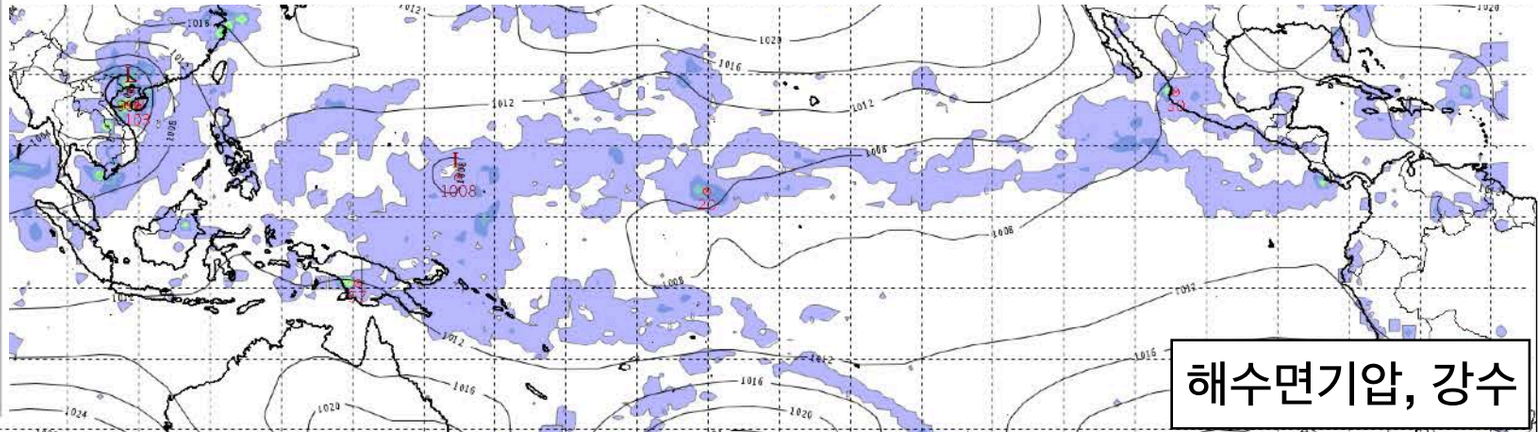
5등급의 슈퍼 태풍 (SSHS)



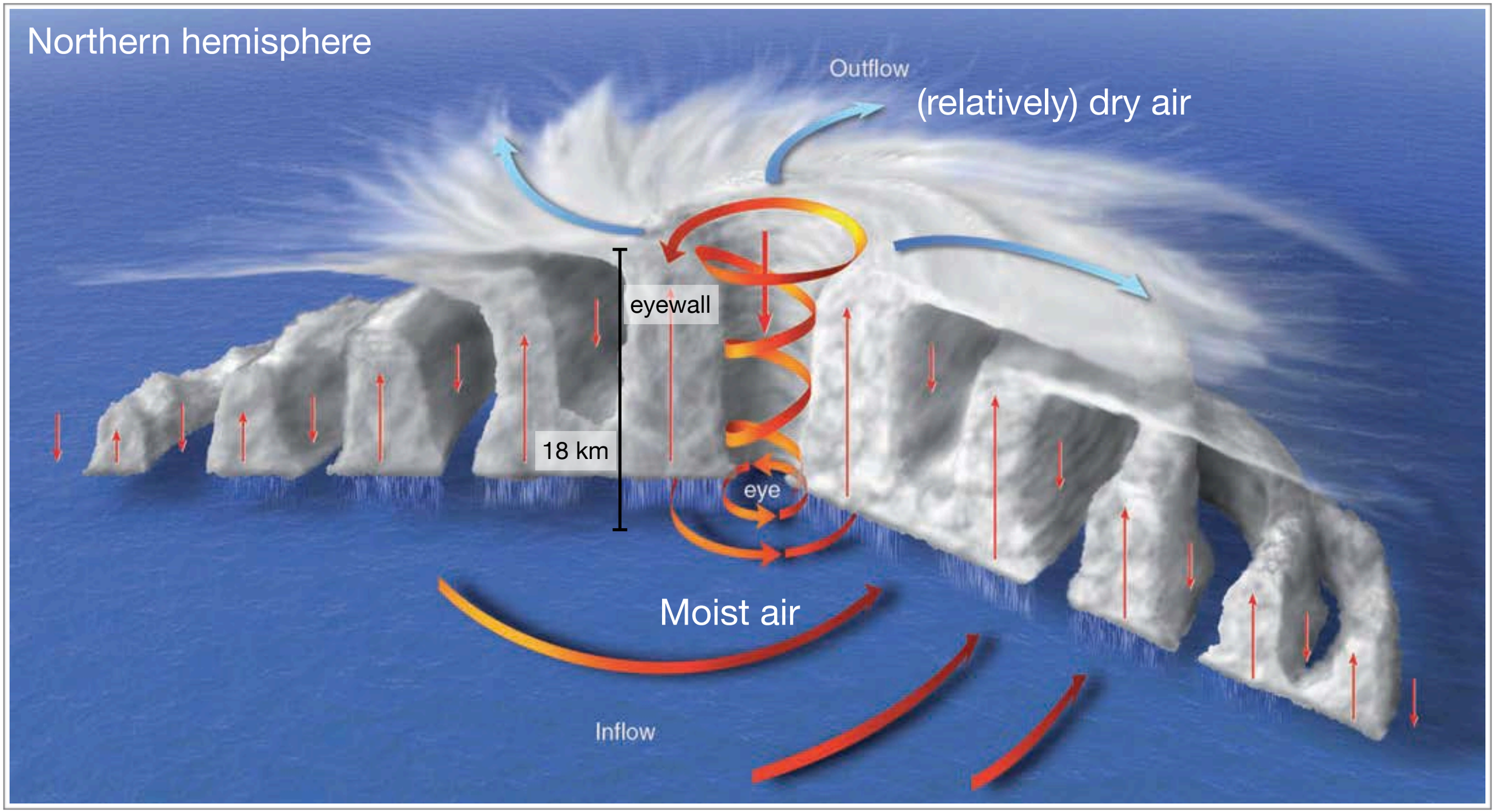


활동 기간		9월 7일 ~ 9월 17일
최저 기압		905hPa
최대 풍속	KMA	56m/s
(10분 평균)	JMA	55m/s (110kt)
태풍 사망자		-



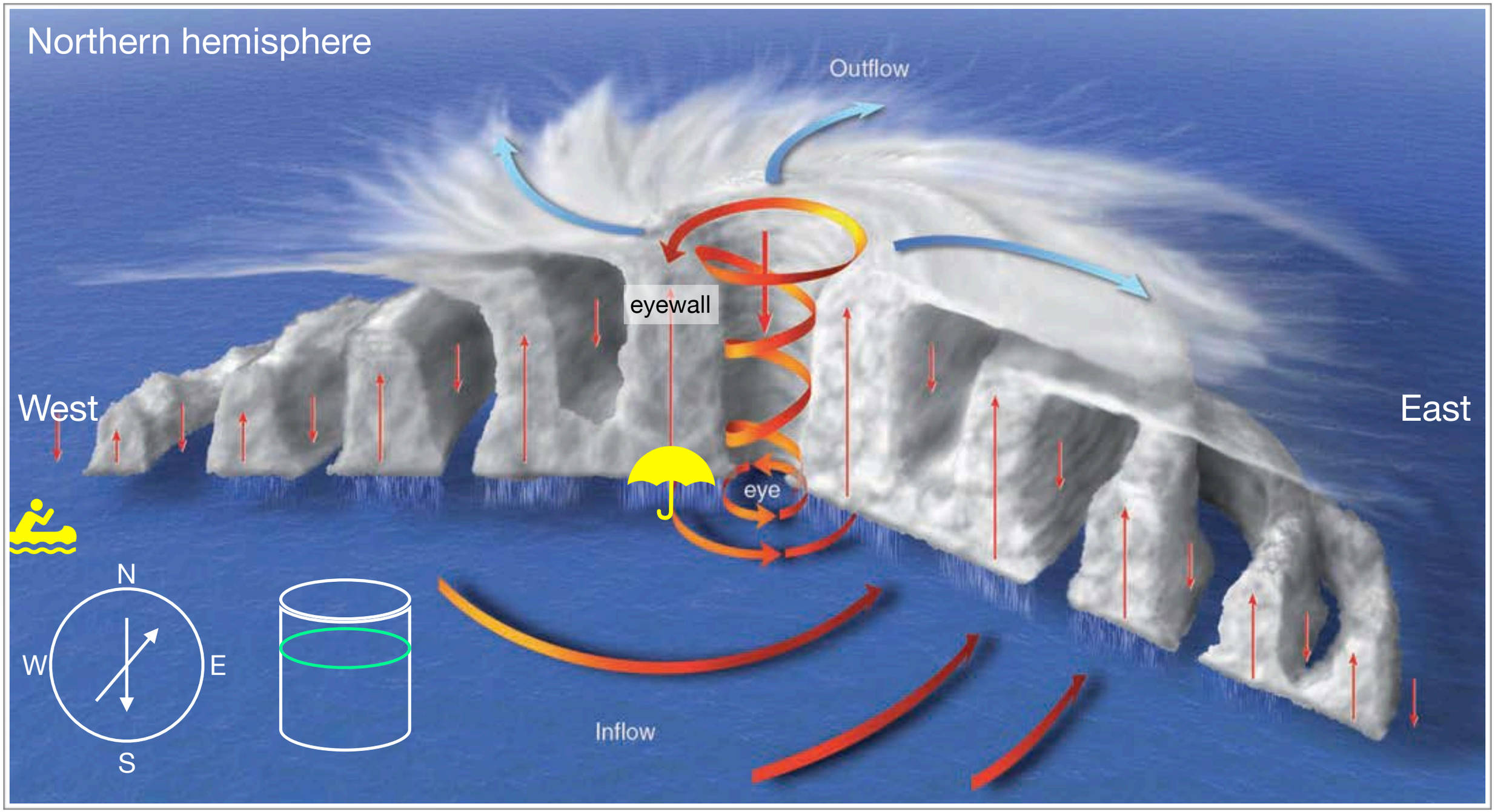


태풍의 구조

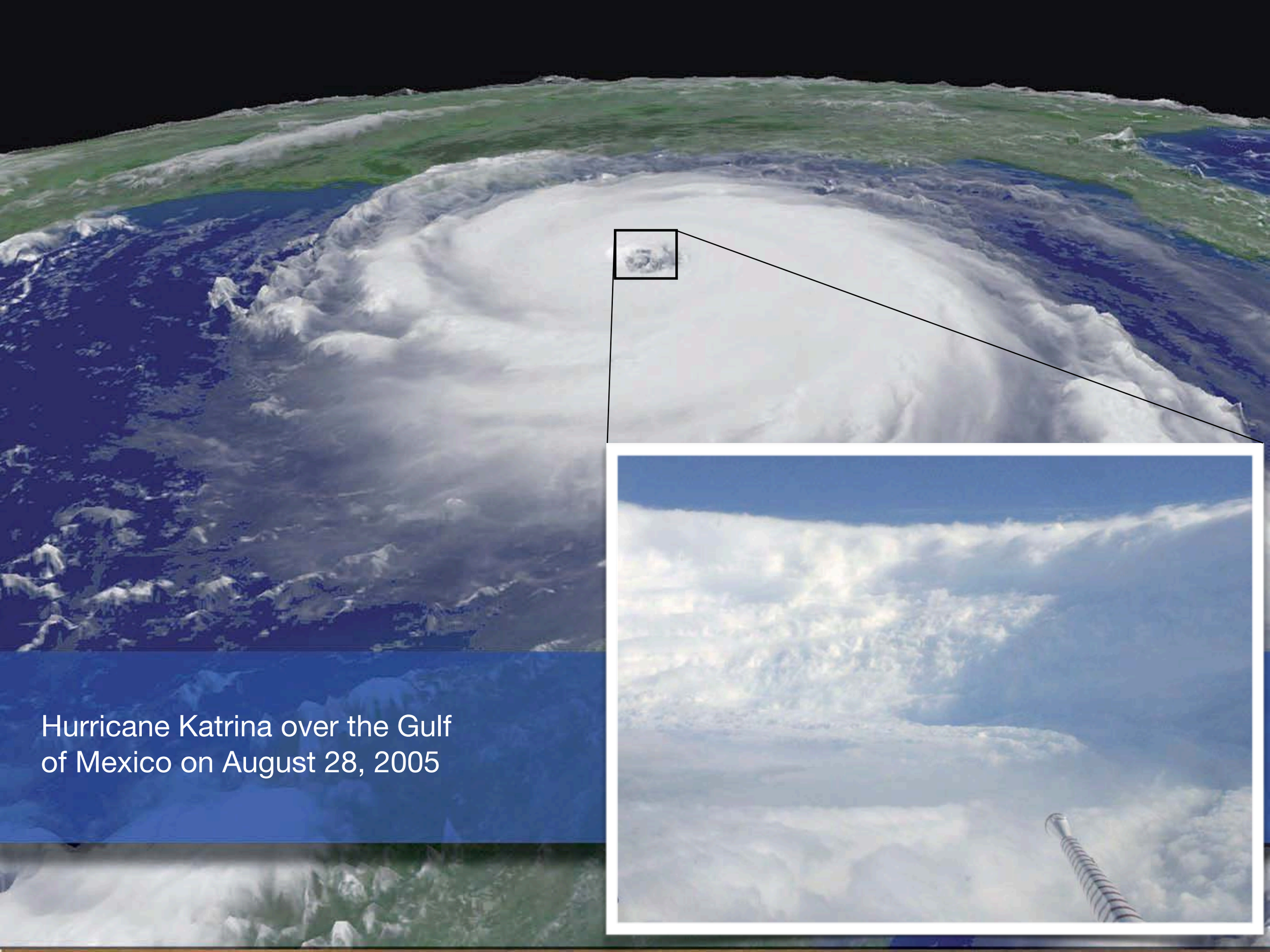

Northern hemisphere
Outflow
(relatively) dry air
eyewall
18 km
eye
Moist air
Inflow

태풍속으로 들어간다면

North

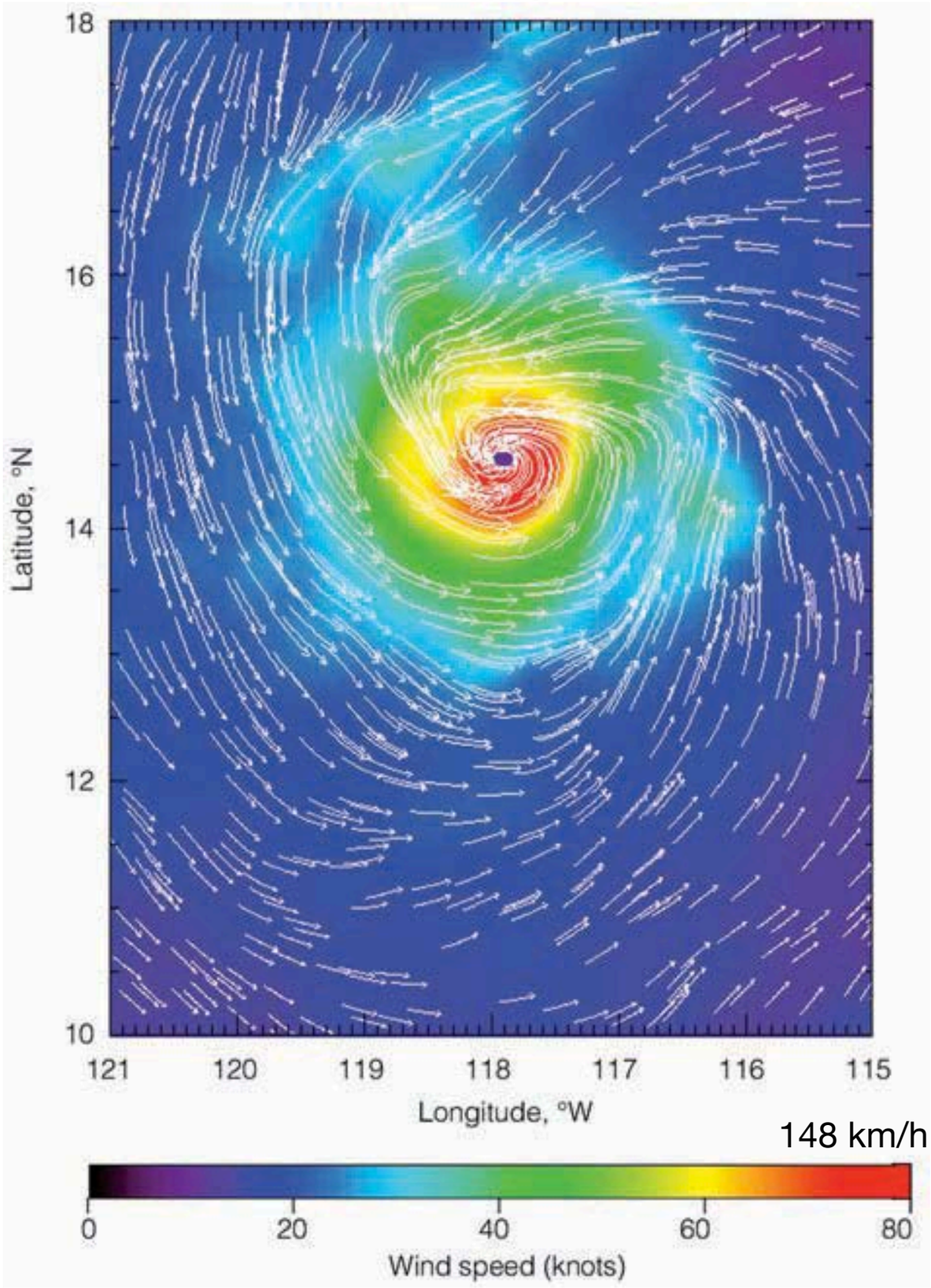


South

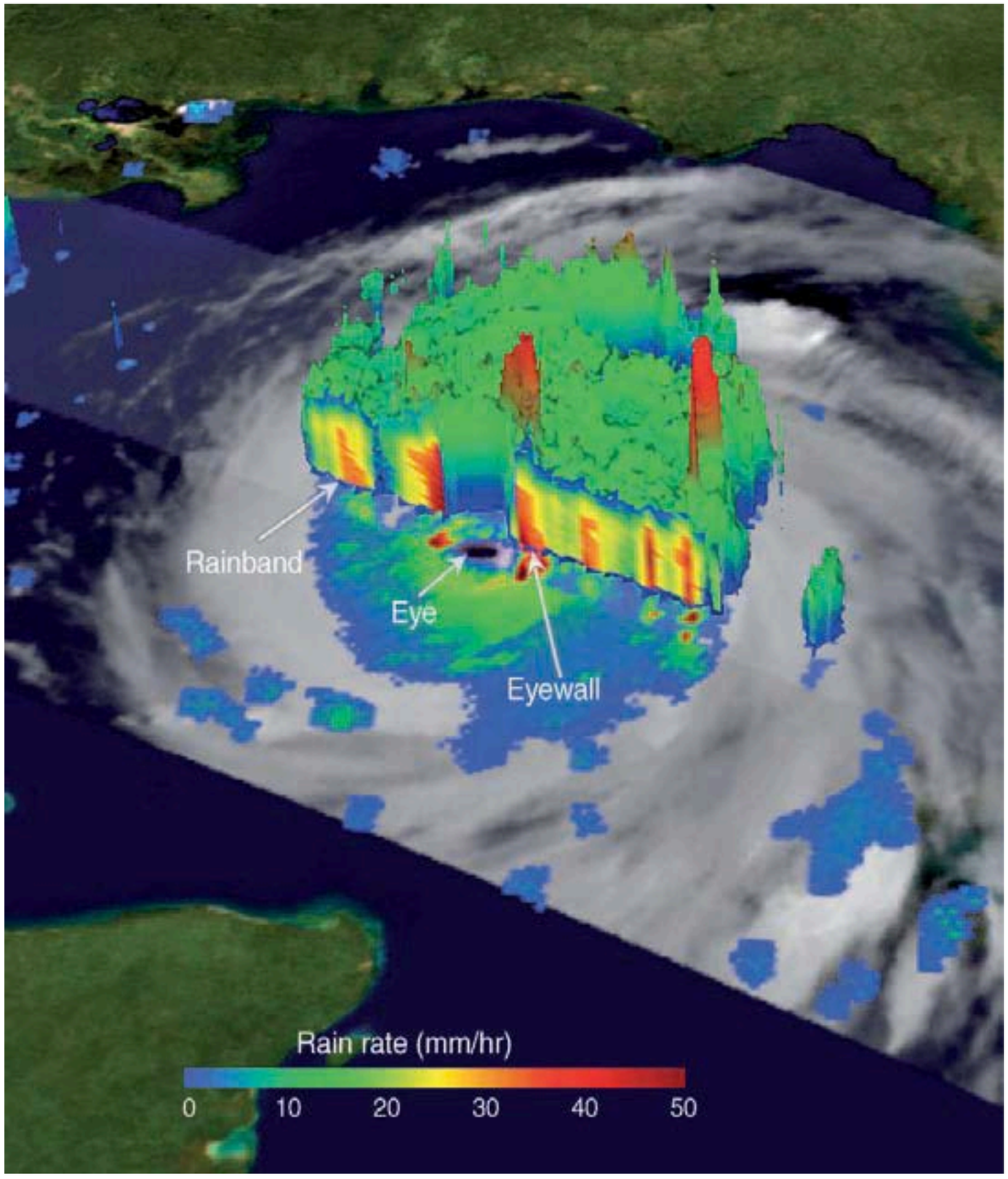


Hurricane Katrina over the Gulf of Mexico on August 28, 2005

Wind



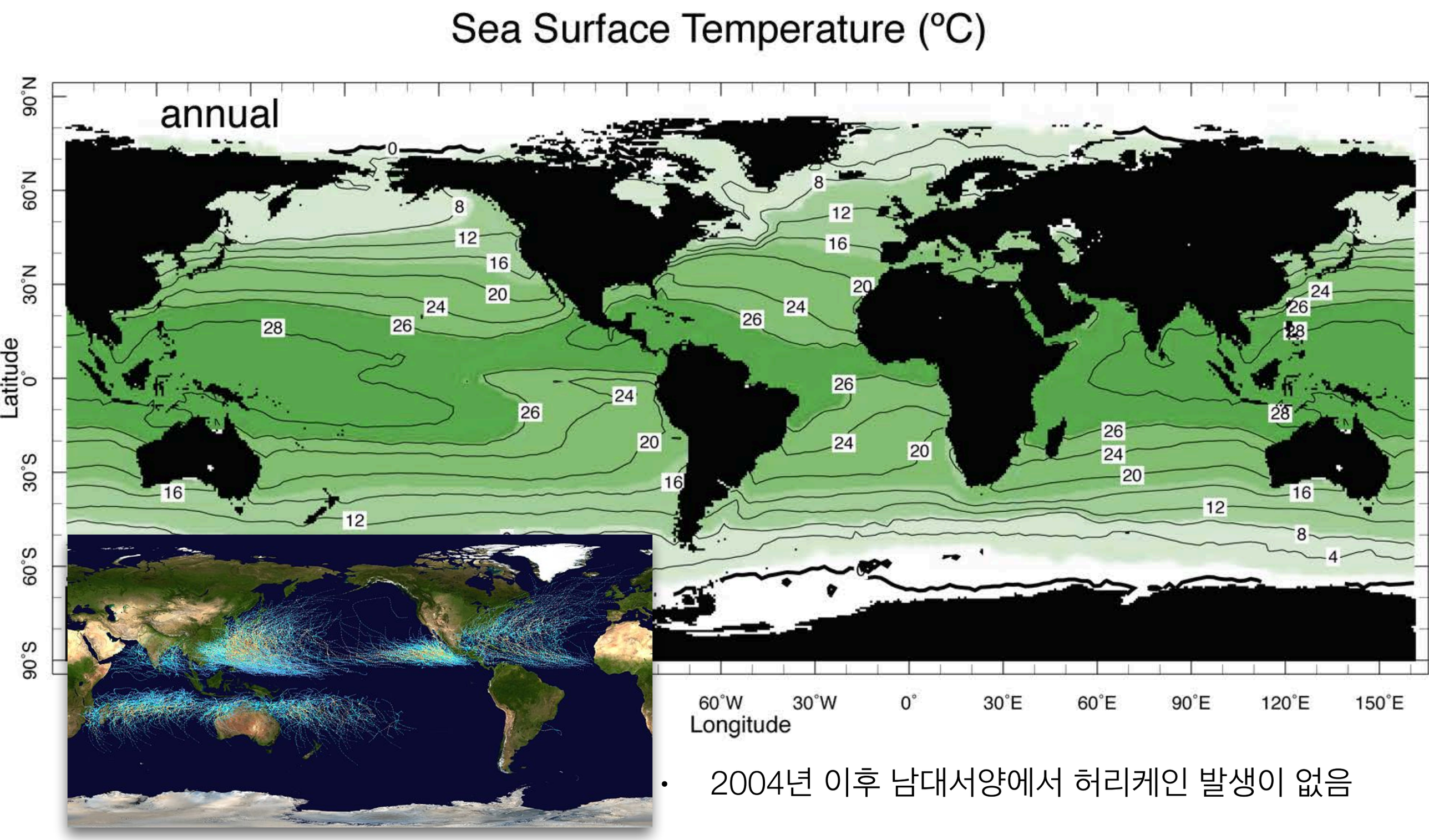
Precipitation rate



태풍이 생성될 수 있는 조건

- 태풍은 열대지방 바다 위에서 아래와 같은 조건일 때 주로 생성
  - 바람이 잔잔할 때
  - 습도가 높을 때
  - 해수면의 온도가 높을 때 (>26.5 °C)
- 공기가 수렴할 때, 전향력으로 회전이 생길 때 생성
  - 적도지역 보다는 5° 에서 20°

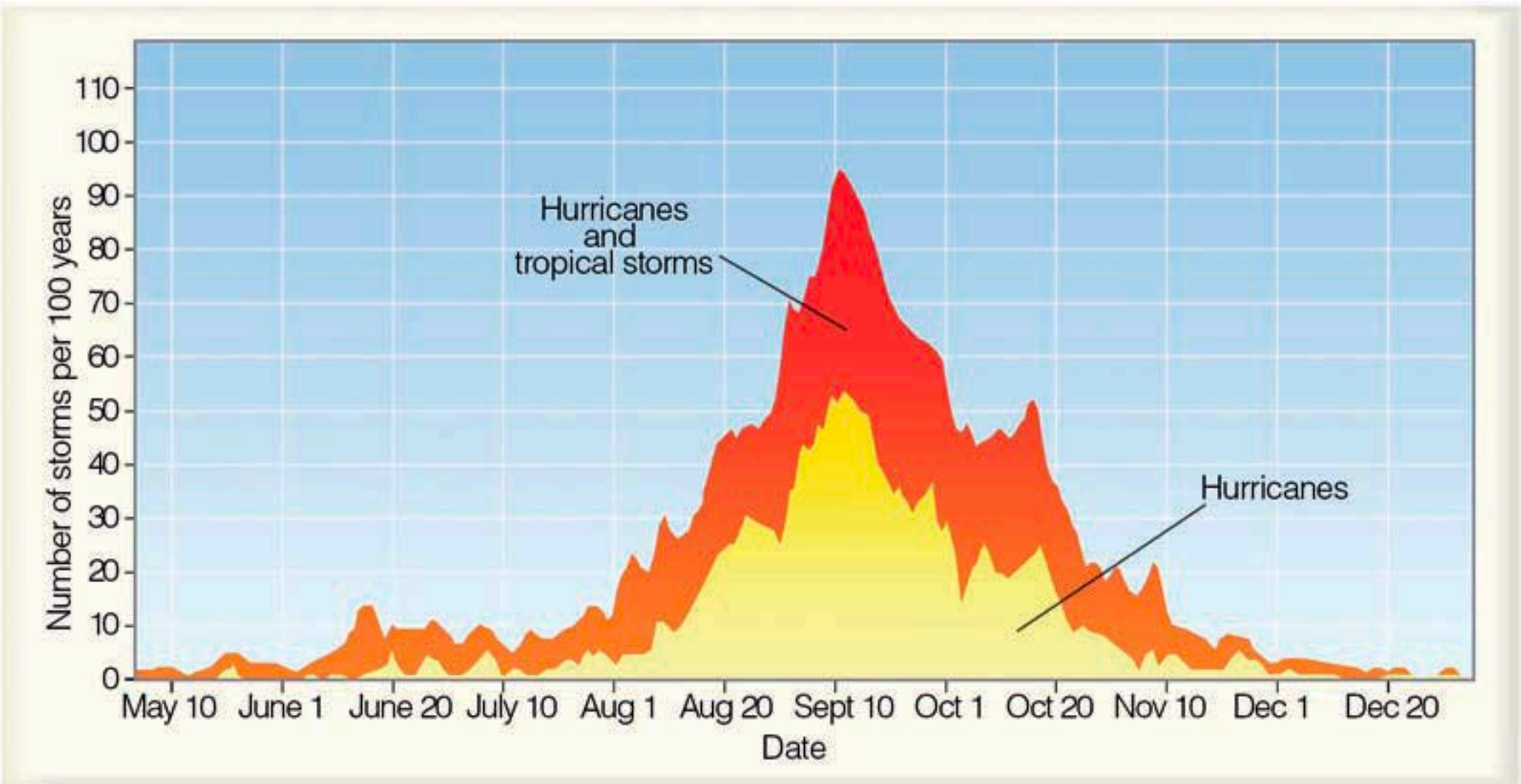
해수면 온도



- 2004년 이후 남대서양에서 허리케인 발생이 없음

태풍(허리케인)이 발생하는 시기

대서양에서 발생하는 허리케인의 월별 수



태풍의 발달

1. 잠열과 현열의 공급
2. 대류지역의 상공이 따뜻해짐
3. 바람이 convection system 밖으로 나감
4. 하층은 공기의 상승으로 압력이 하강.
5. 북반구에서는 반시계방향의 회전과 함께 바람이 convection system 중심부로 불게 됨
6. 회전지역의 영역이 줄어들며, 바람의 세기가 강해짐
7. 마찰력 증가로 바람이 더욱 등압선을 가로질러 저기압으로 향함
8. 바람과 함께 수증기와 열 공급

태풍의 발달

- 태풍의 발달은 에너지를 요구함
- 에너지의 원천
  - 바다에서 오는 현열

$$Q_S = \rho_{air} c_p c_S u_{10} (SST - T_{air})$$

  - 수증기의 응결에 의한 잠열

$$Q_L = \rho_{air} L_e c_L u_{10} (q^*(SST) - q_{air})$$

태풍의 발달

$$Q_S = \rho_{air} c_p c_S u_{10} (SST - T_{air})$$

$$Q_L = \rho_{air} L_e c_L u_{10} (q^*(SST) - q_{air})$$

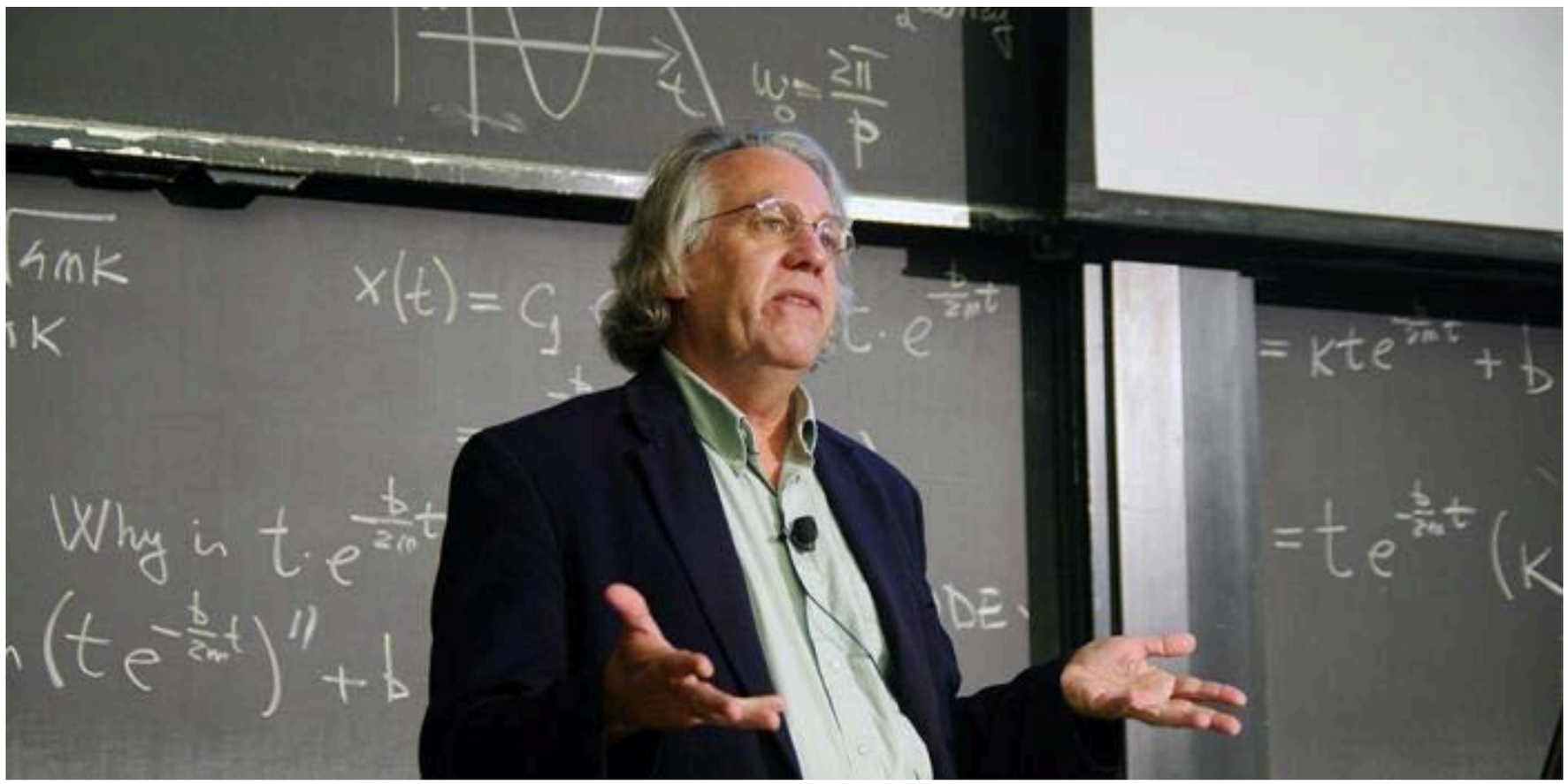
- 해수면의 온도가 높으면 높을수록 잠열과 현열이 커짐
- 바람이 세면 셀수록 잠열과 현열이 커짐
- 바람은 태풍 중심부로 갈 수록 빨라지고, 따라서 더 많은 에너지가 공급됨

태풍의 발달

- 에너지는 따뜻한 물에서 하층 구름으로 공급
- 에너지는 상층구름에서 복사열의 형태로 방출
- 얻은 열과 방출하는 열의 차이가 곧 태풍이 사용한 에너지량
- 즉, 상층/하층 구름의 온도 차이로 (T_{bottom} - T_{top}) 태풍이 사용한 에너지량을 예상할 수 있음.
- 따라서 따뜻한 물은 곳 T_{bottom} 을 상승시키고, 태풍이 많은 에너지를 사용할 수 있도록 함

A short lecture by Prof. Kerry Emanuel, MIT

- https://youtu.be/aR7a3ET5uws#t=22m47s



태풍의 생성을 방해하는 요인

- 하강기류: 위도 20° 위에는 해들리 순환의 하강기류가 위치하므로 태풍이 발달하기 어려움

- 강한 상층 기류: 하층과 상층의 바람세기 및 방향이 다르면 shear가 발생하여 태풍에서 발달하는 대류를 방해하고 세력이 약해지게 함.

- 열과 수증기가 공급되지 않으면 에너지 원천이 없어지므로 소멸함

태풍의 소멸

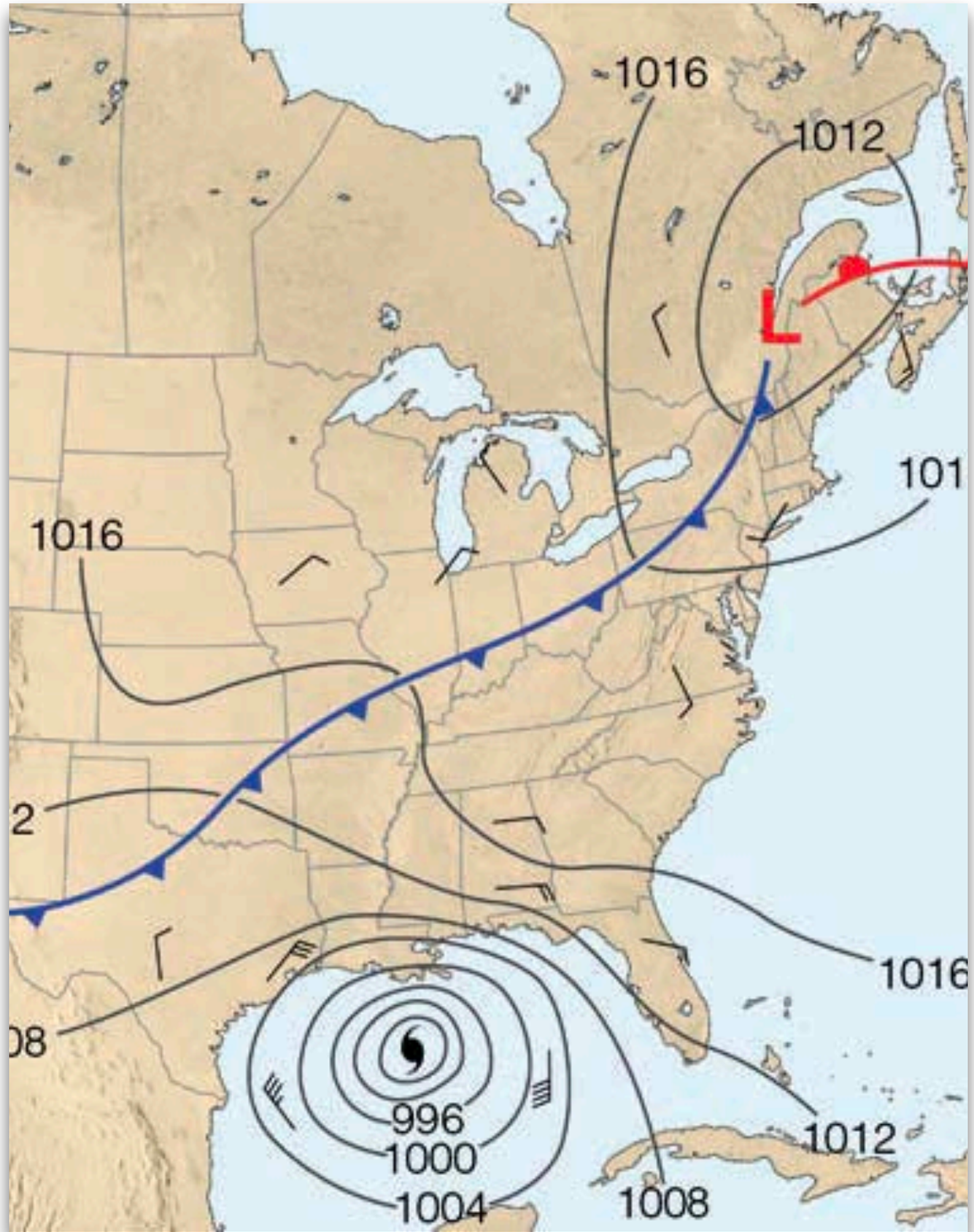
- 태풍은 에너지 공급을 받지 못하면 소멸함
  - 차가운 해수 위
  - 따뜻한 물이 차가운 물 위에 얇게 분포할 때
    - 태풍의 강한 바람이 해수를 연직으로 섞어주기 때문에, 차가운 물이 해수면으로 공급되면서 태풍 소멸
  - 천천히 움직일 때 (연직혼합으로 해수면 온도 하강)

태풍의 소멸

- 상륙을 하면 소멸함
  - 에너지 공급이 끊김
  - 지면과의 마찰
- 연직으로 바람의 shear가 클 때

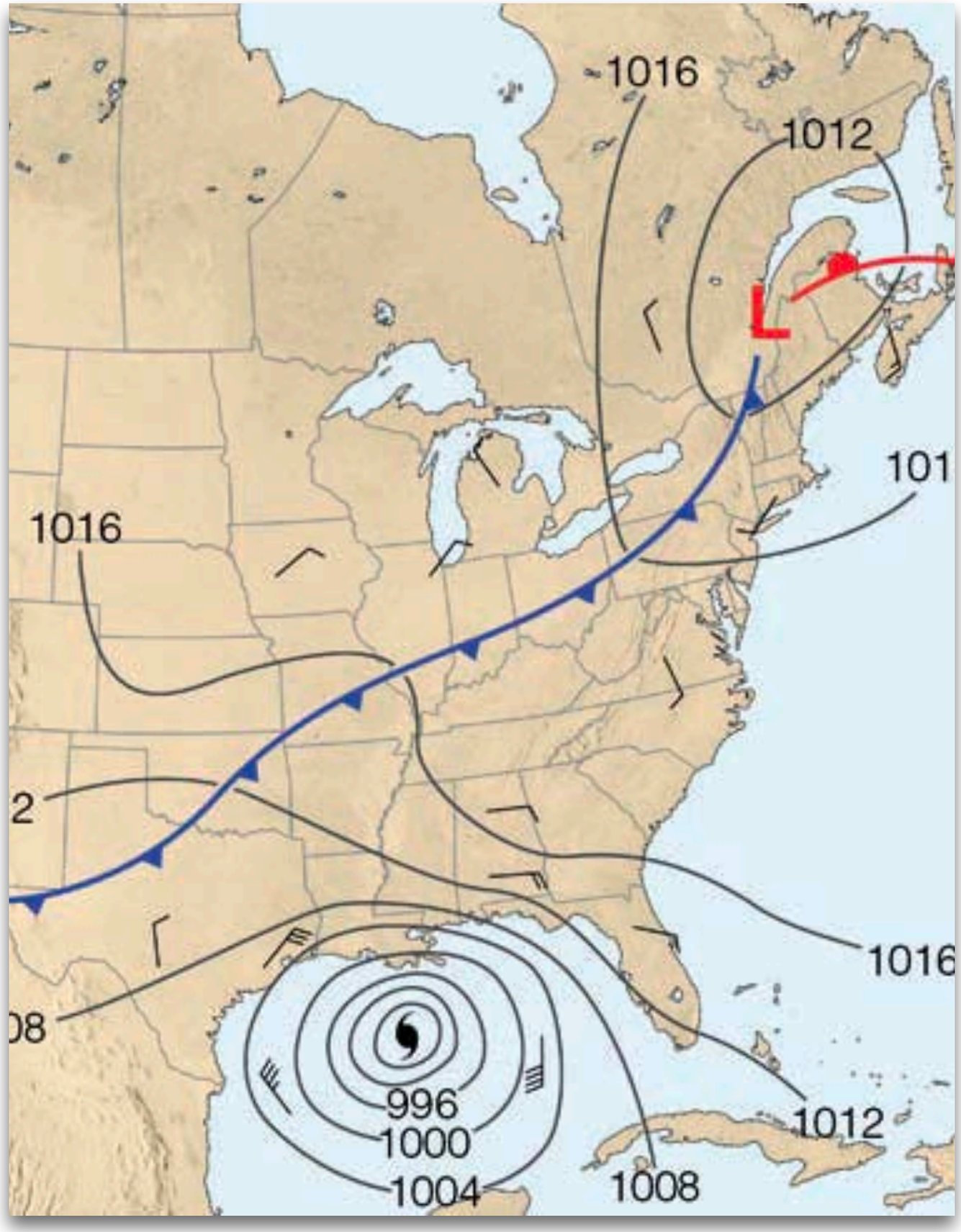
Hurricanes v.s. mid-latitude cyclones

- Energy source
  - Hurricanes: warm water
  - Mid-latitude cyclones: horizontal temperature gradient
- Center
  - Hurricanes: warm-core lows
  - Mid-latitude cyclones: cold-core lows



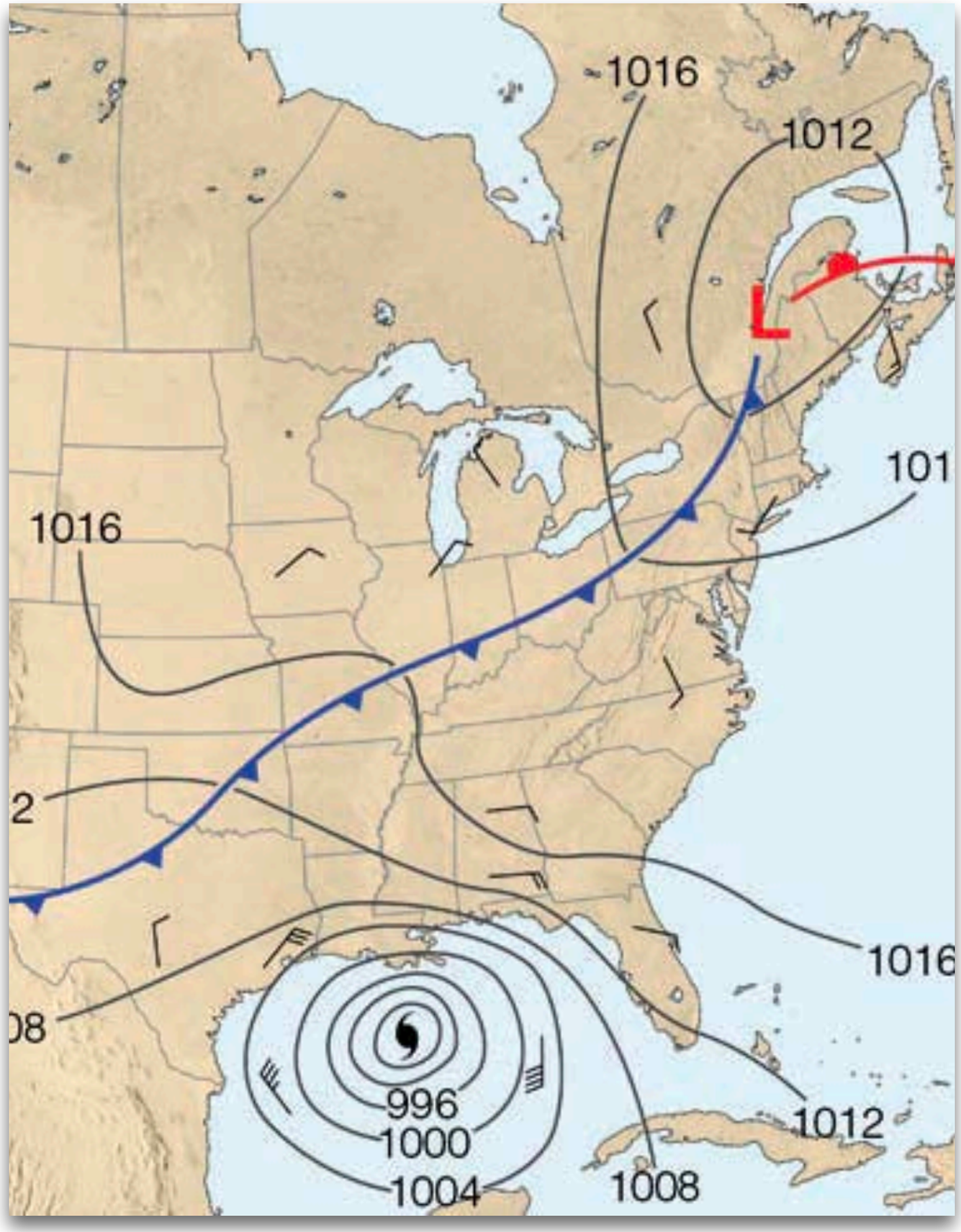
태풍과 중위도 저기압

- 연직 운동
  - 태풍 : 태풍의 눈이 존재할 때 공기의 하강
  - 중위도 저기압: 상승 공기
- 바람
  - 태풍 : 지상에서 바람이 더 강함
  - 중위도 저기압 : 상층에서 바람이 더 강함



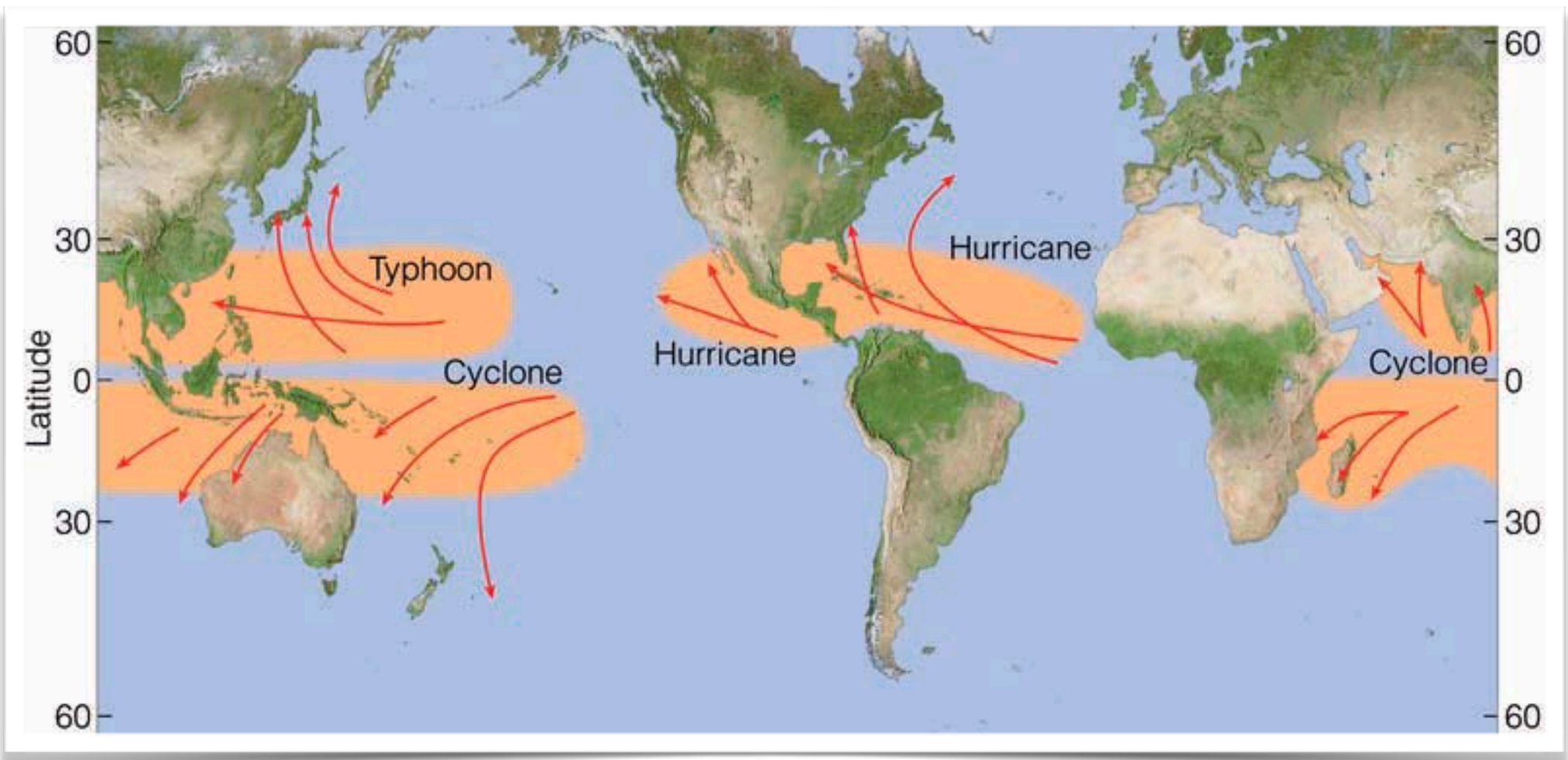
태풍과 중위도 저기압

- 등압선
  - 태풍: 원형의 등압선, 기압경도력이 강하다
  - 중위도 저기압: 전선이 발달하고 기압경도력은 상대적으로 약하다.
- 유사점
  - 지표면에서 저기압으로 나타남
  - 반시계방향의 바람



태풍의 이동

- 천천히 (10 knots = 18 km/h) 약 1주일 동안 서진
- 북향, 혹은 동북향으로 방향을 바꾸며 이동속도를 높임
- 날씨가 경로에 영향을 줄 수 있음



허리케인의 이름

- 1953년부터, the National Weather Service 는 허리케인의 이름을 알파벳 순서로 나열된 여성의 이름으로 지음
- 1978년, 동태평양에서 발달하는 열대성 저기압에 영어, 스페인어, 프랑스의 남성/여성 이름을 알파벳 순서대로 붙여줌
- 1979년부터 북대서양에서 발생하는 열대성 저기압도 같은 방법으로 명명
- 6 세트의 이름이 순차적으로 사용되고 있음
- 만약 허리케인의 세기가 카테고리 3 이상이어서 많은 피해를 주었다면 그 이름은 최소 10년동안 다시 쓰지 않음

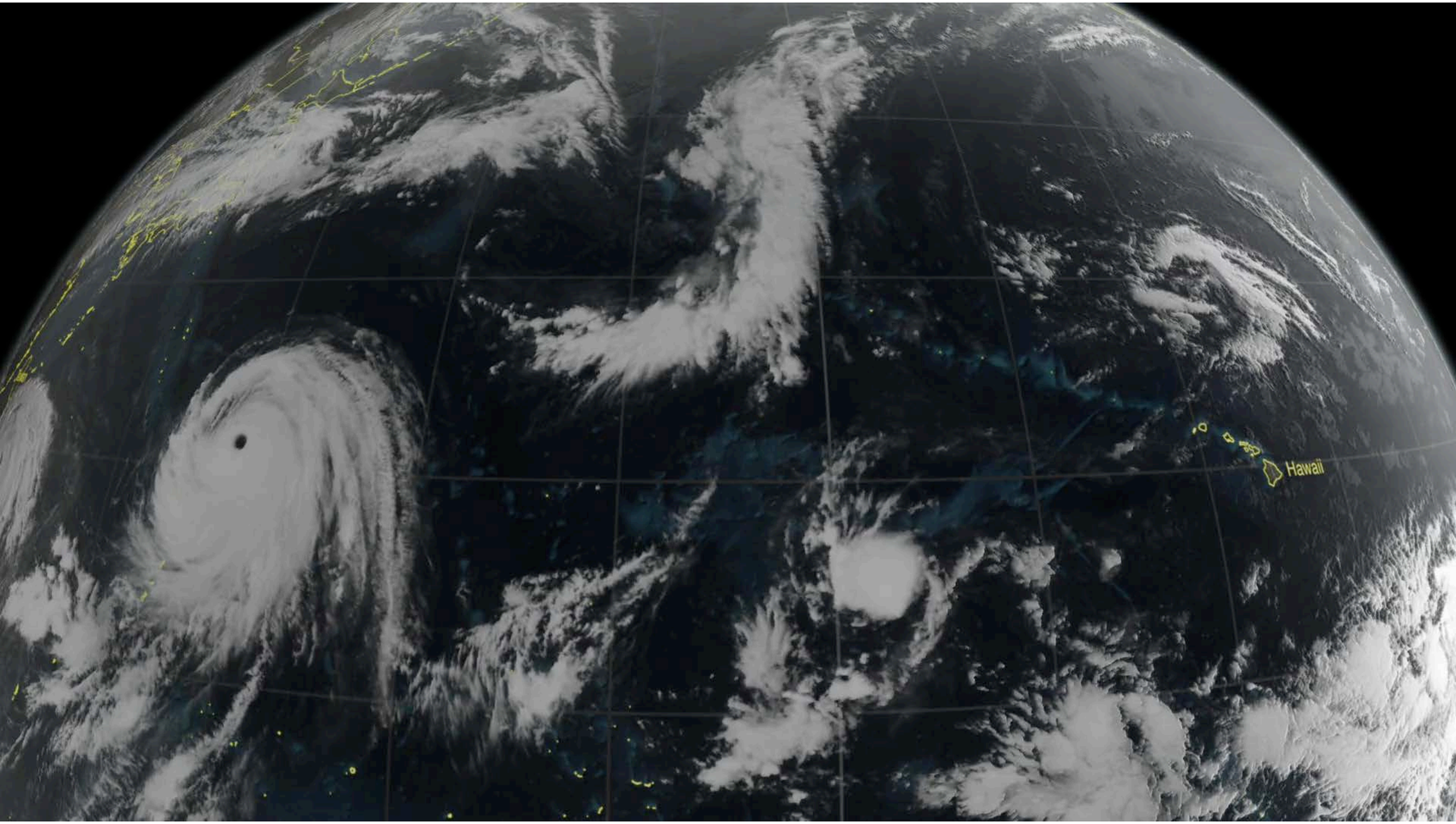
태풍의 이름

- 2000년 이전에는, Joint Typhoon Warning Center에서 84개의 이름을 태풍에게 붙여줌
- 2000년 이후에는, Regional Specialized Meteorological center in Tokyo 에서 140개의 이름 들 중 선택 (10 names from 14 countries).
- 140개의 이름을 5세트로 나누고, 이 이름들을 순차적으로 사용
- 한국이 제공한 이름들: ‘개미', ‘나리', ‘장미', ‘미리내', ‘노루', ‘제비', ‘너구리', ‘고니', ‘메기', ‘독수리'

From a hurricane to a typhoon

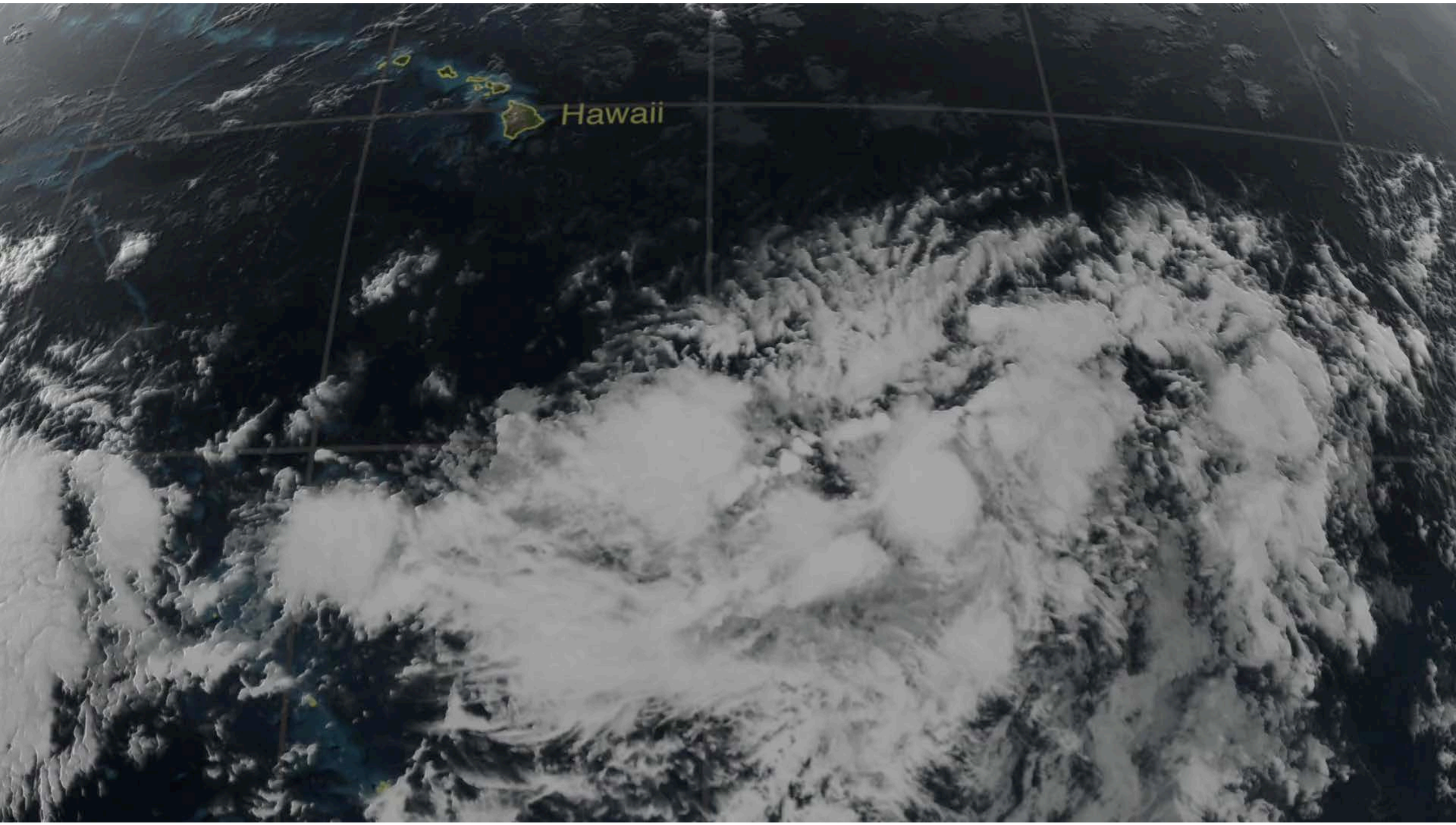
- If the hurricane remains over the warm water, it may survive for a long time.
- Kilo (August, 2015)
  - formed in the eastern North Pacific and traveled to the western North Pacific crossing the international dateline.
  - It was sustained for 21 days.

A track of Kilo



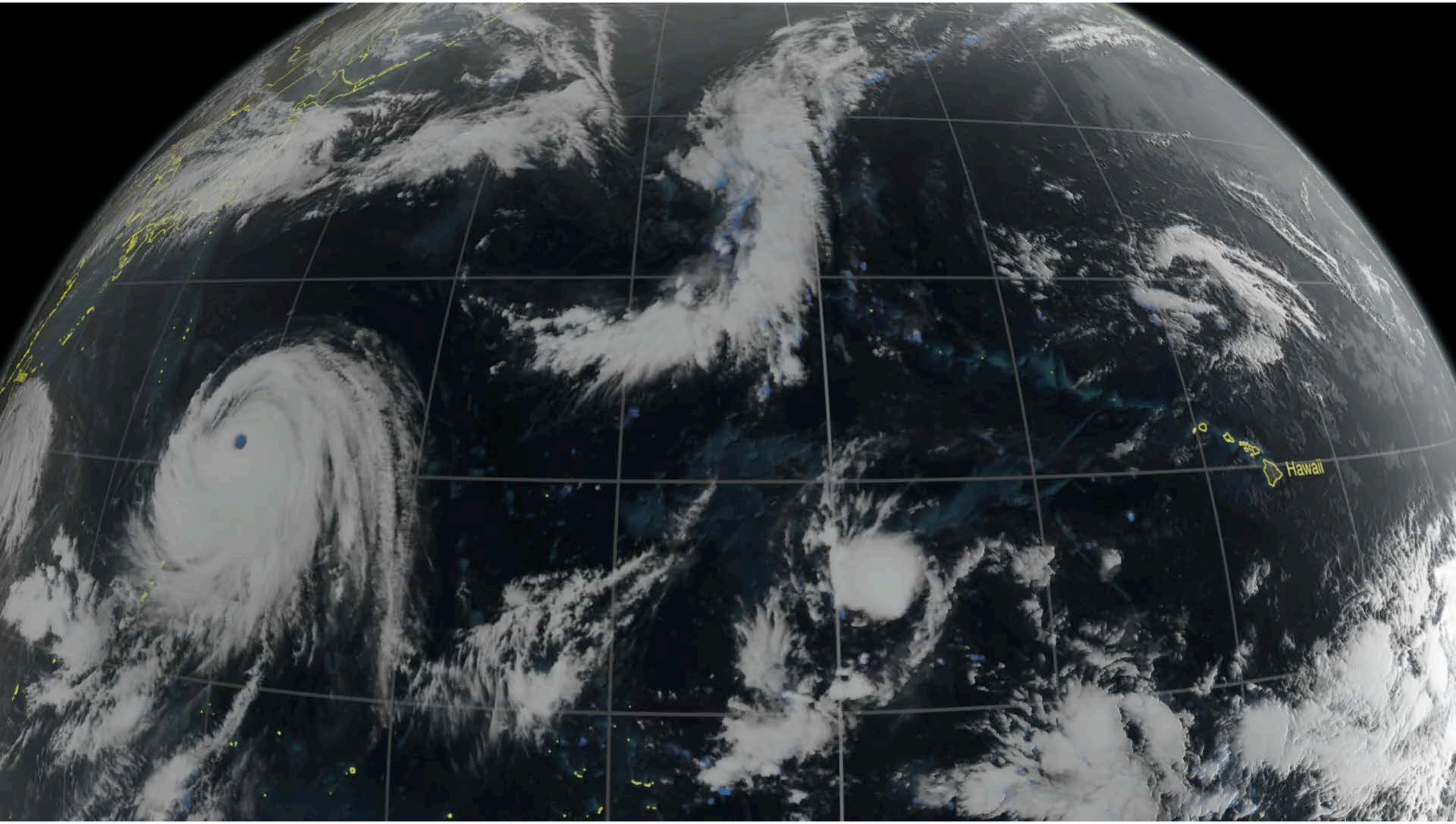
From https://svs.gsfc.nasa.gov/4358

A track of Kilo: Close up



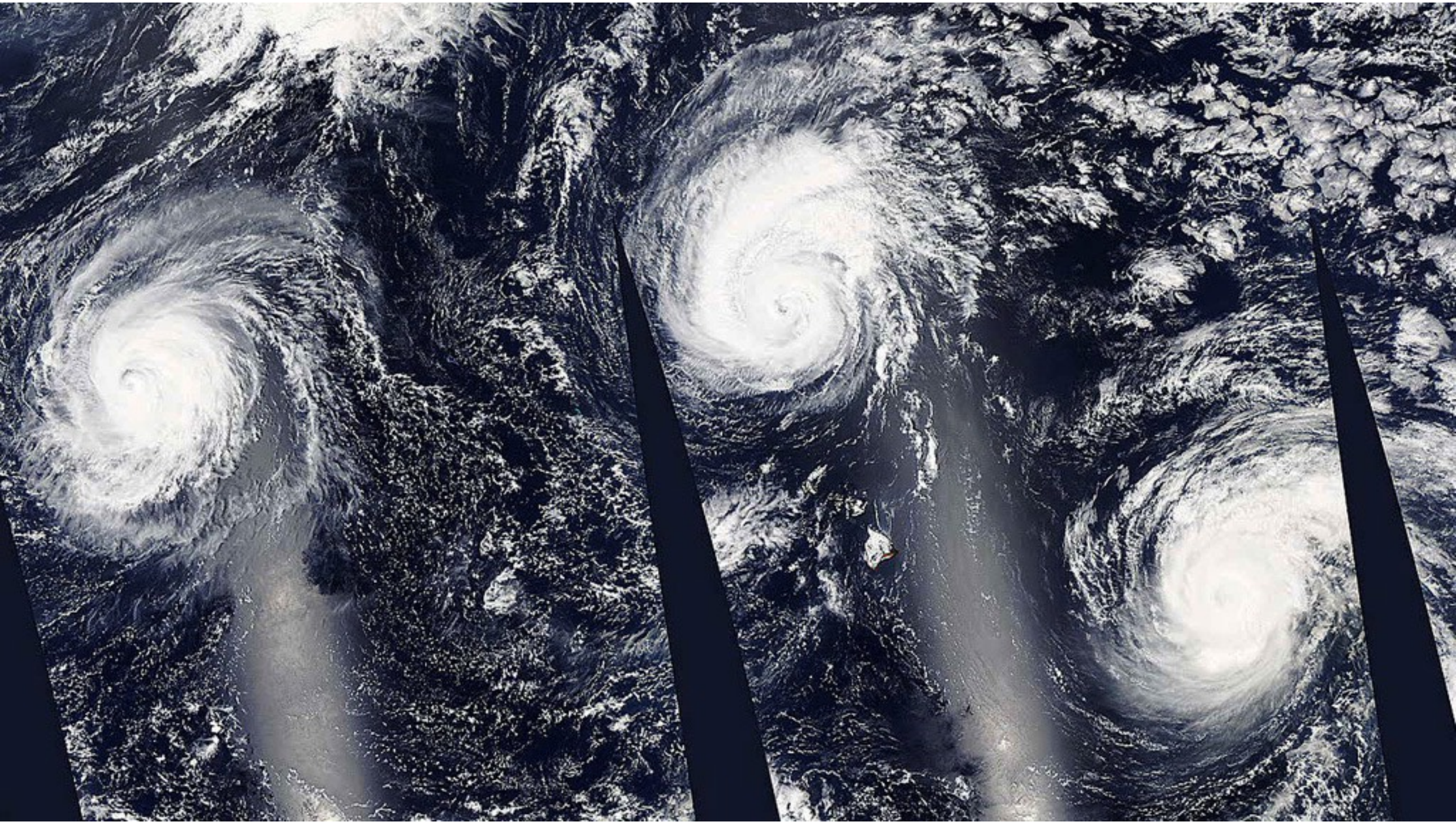
From https://svs.gsfc.nasa.gov/4358

A track of Kilo: Precipitation



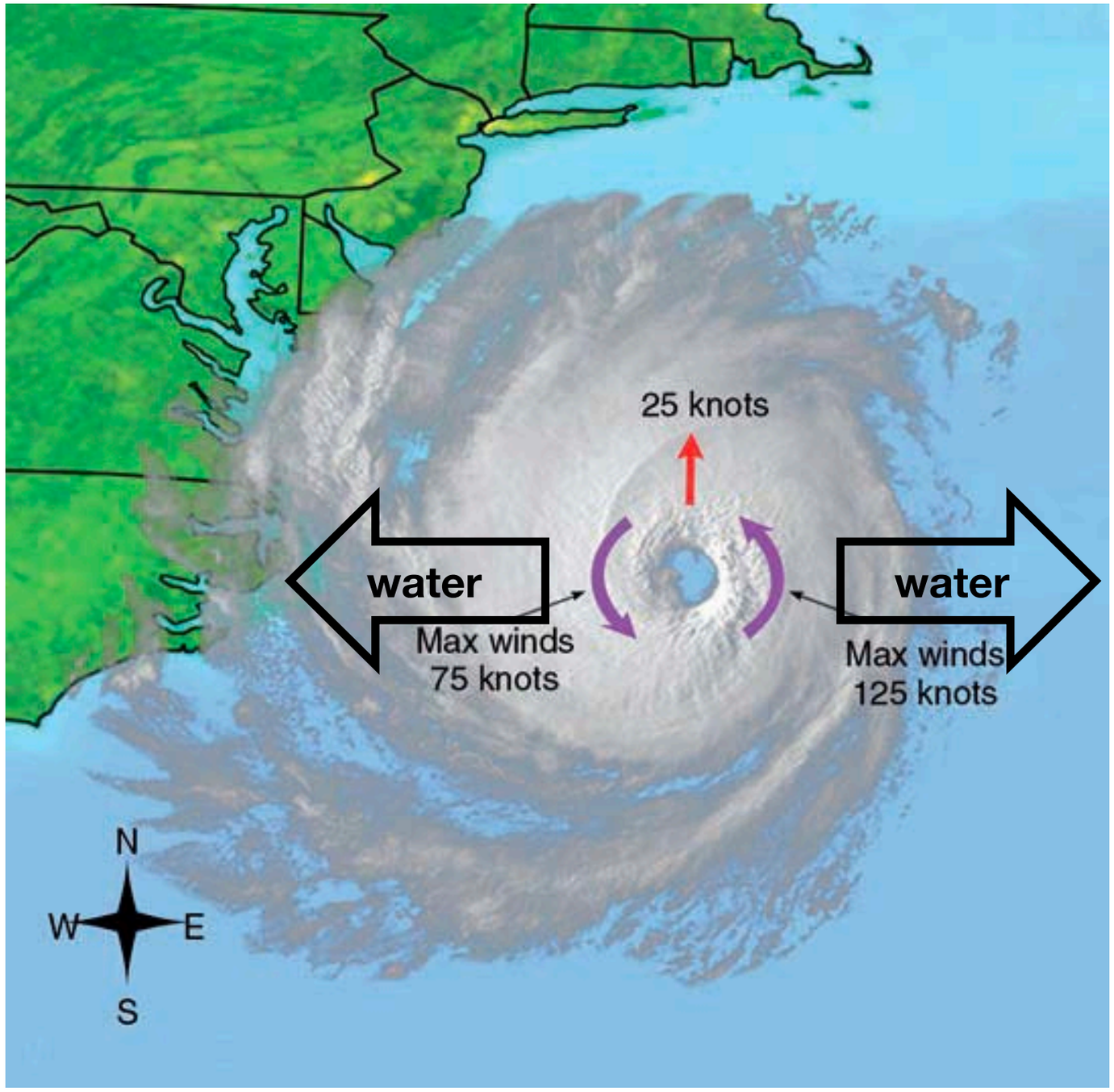
From https://svs.gsfc.nasa.gov/4359

Three in a row!



Kilo **Ignacio** **Jimena**

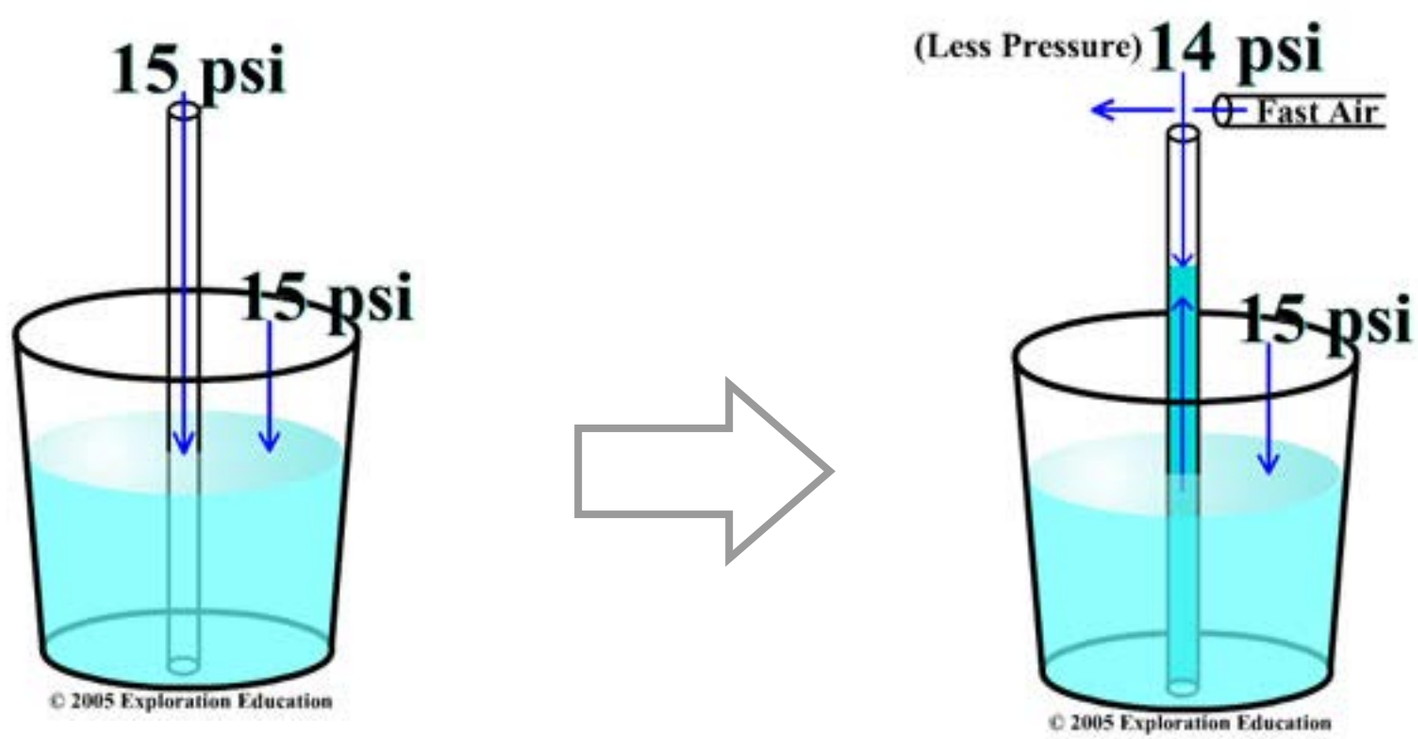
태풍의 피해



with winds of 100 knots swirling counterclockwise about its center

스톰 서지 (Storm surge)

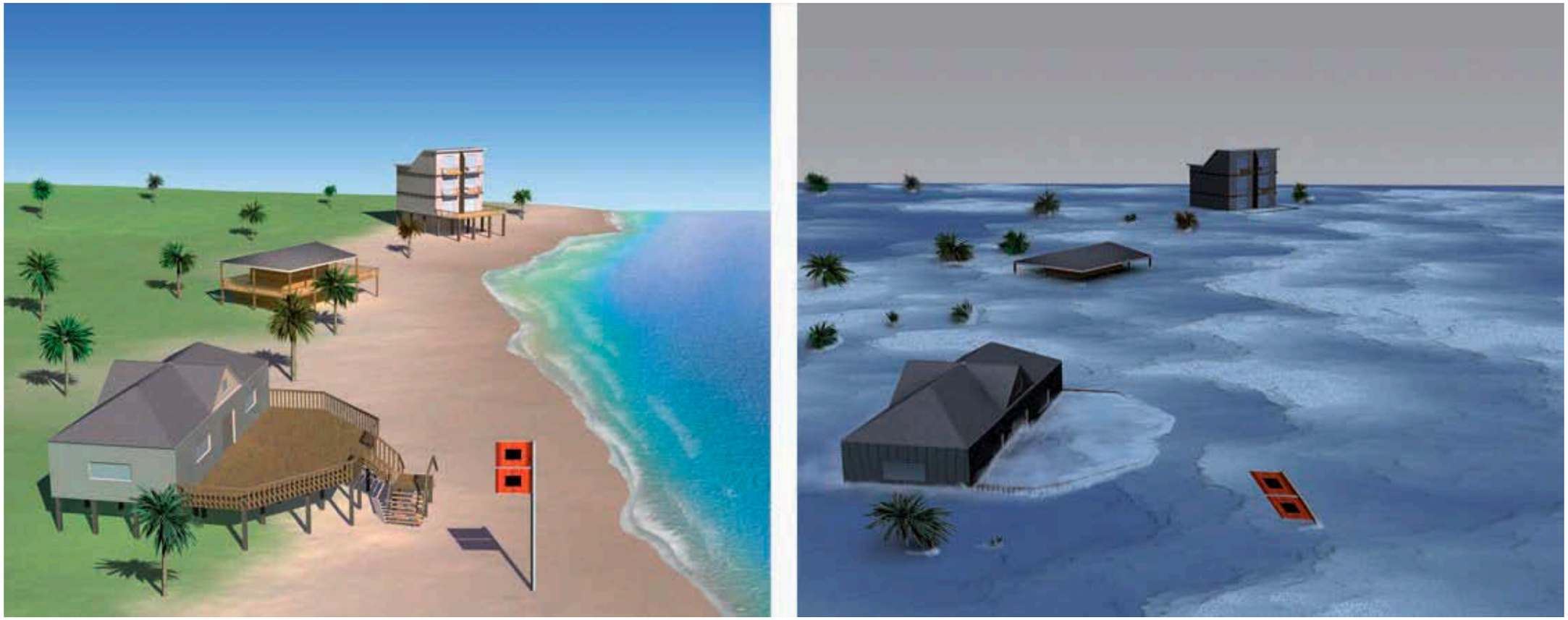
- Ekman transport + High waves + Low pressure $\Longrightarrow$ storm surge



스톰 서지 (Storm surge)

- Ekman transport + High waves + Low pressure $\Longrightarrow$ storm surge

- Storm surge + rain (+ high tide) $\Longrightarrow$ flooding

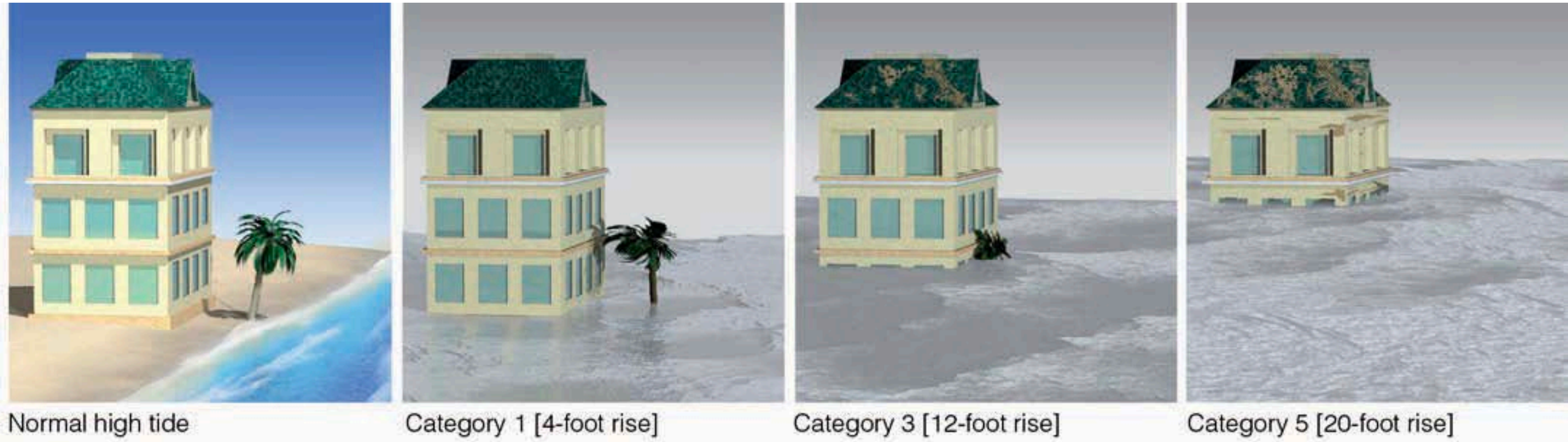


Categorizing hurricanes

- Saffir-Simpson scale

category	Central pressure	Winds		storm surge	
	mb	mph	knots	ft	m
1	>=980	74-95	64-82	4-5	~1.5
2	965-979	96-110	83-95	6-8	~2.0-2.5
3	945-964	111-130	96-113	9-12	~2.5-4.0
4	920-944	131-155	114-135	13-18	~4.0-5.5
5	<920	>155	>135	>18	>5.5

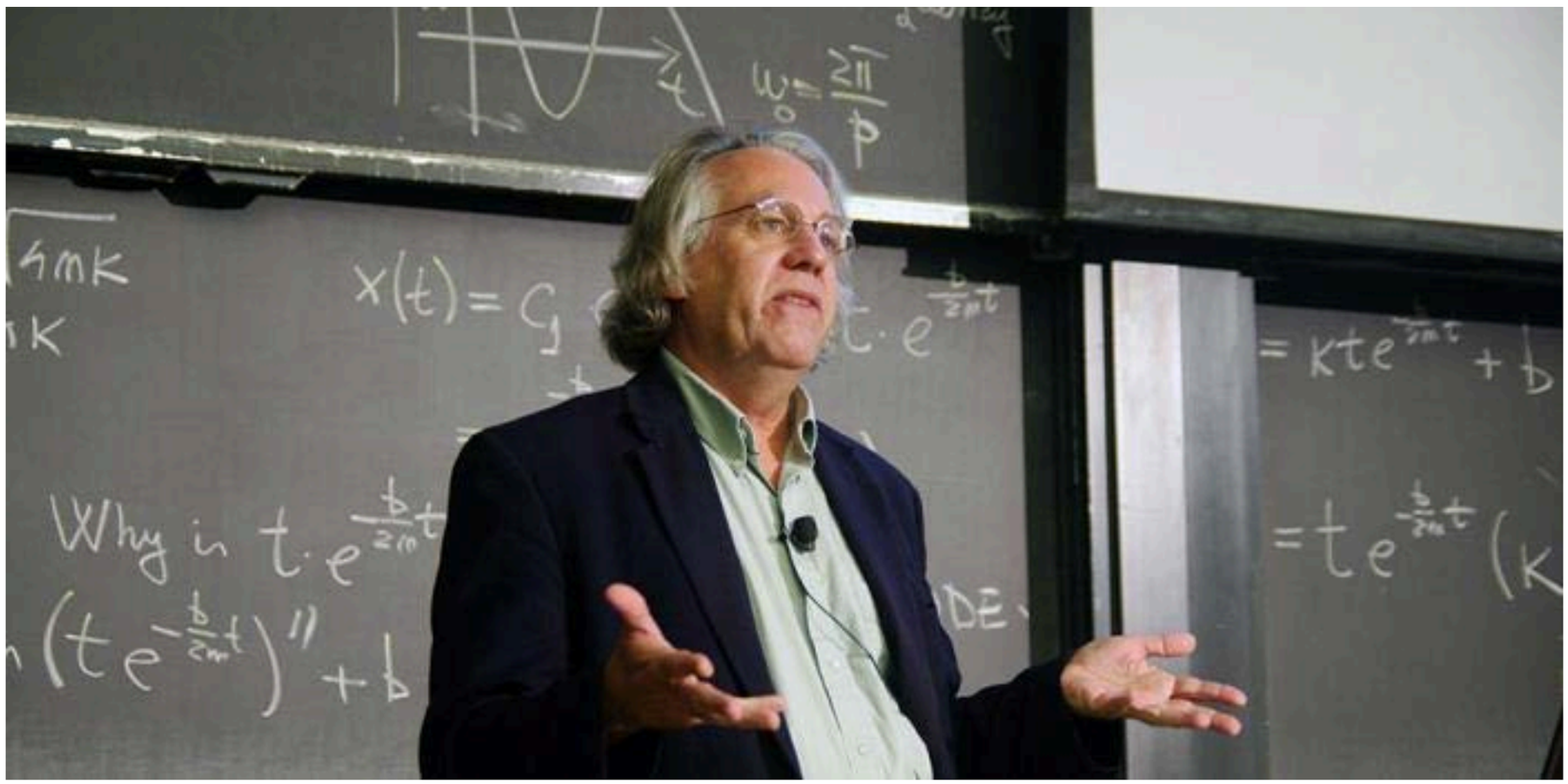
Categorizing hurricanes



Major hurricanes

Talk by Professor Kerry Emanuel at MIT

- video



More vulnerable to hurricanes

Miami Beach 1926

Wendler Collection

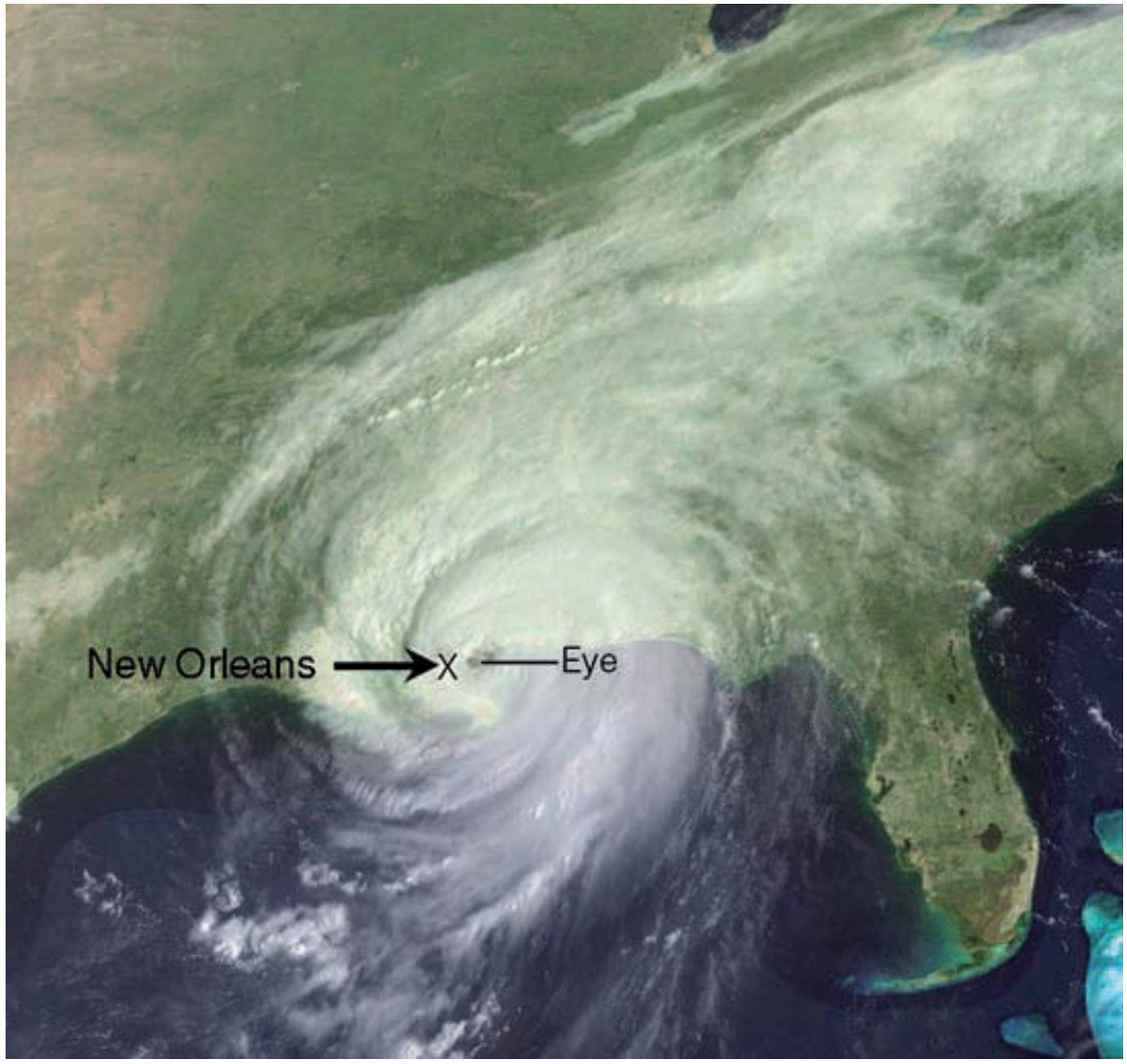
Miami Beach 2006

Joel Gratz © 2006

BAS serco

Hurricane Katrina, 2005

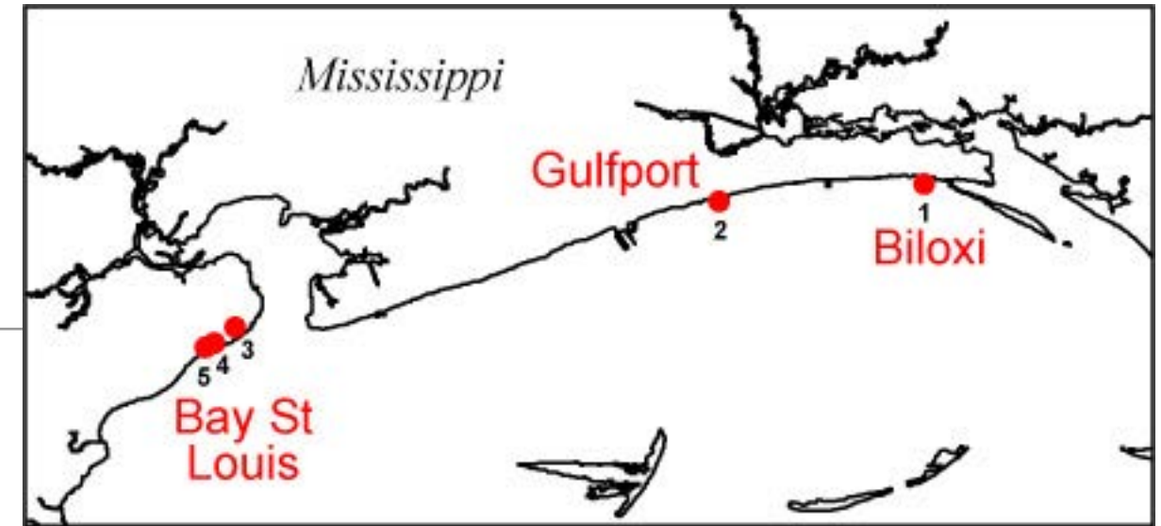
August 29, 2005

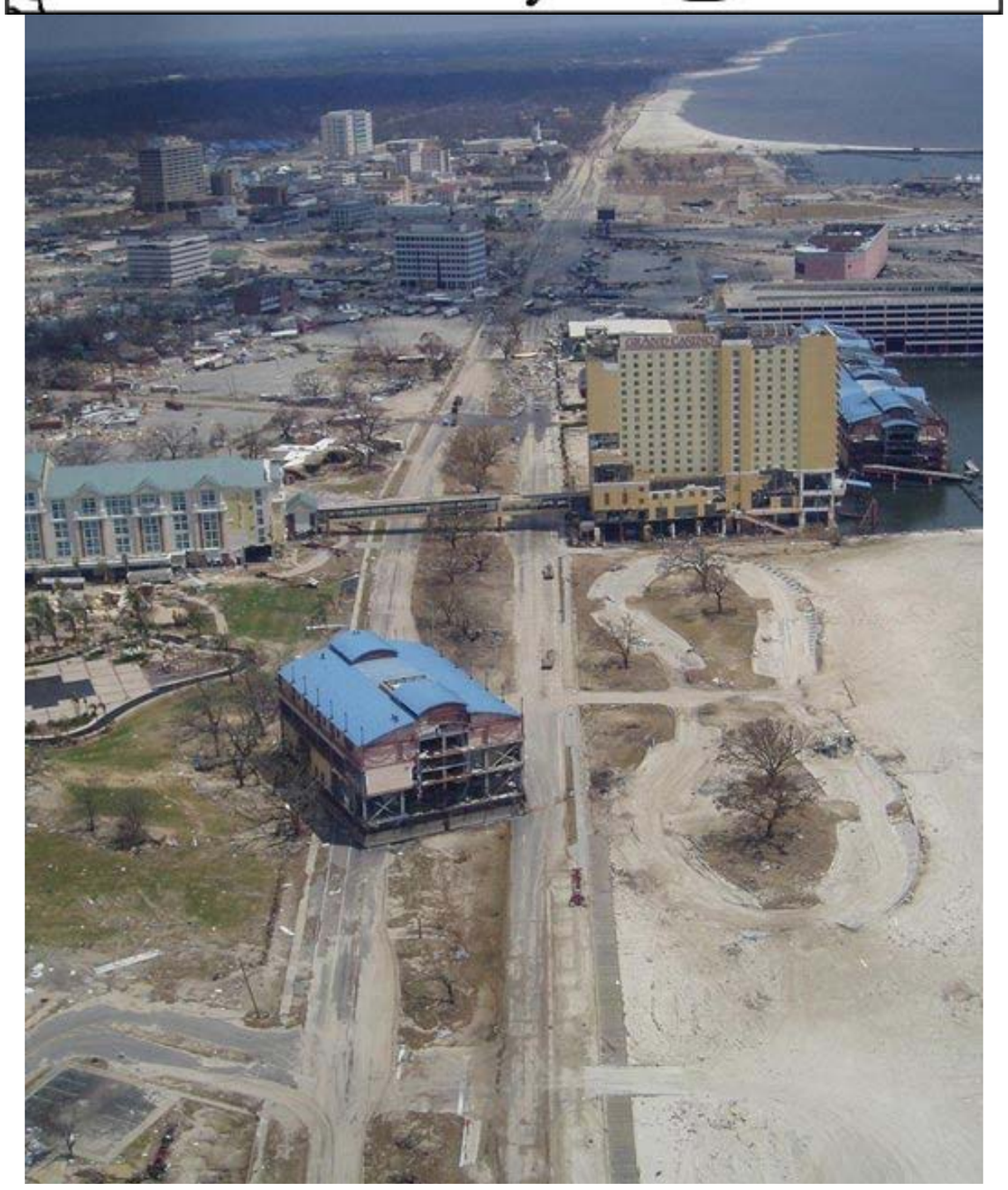


At landfall, Katrina had sustained winds of 110 knots, a pressure of 920 mb, and a storm surge over 20 feet (6 m).

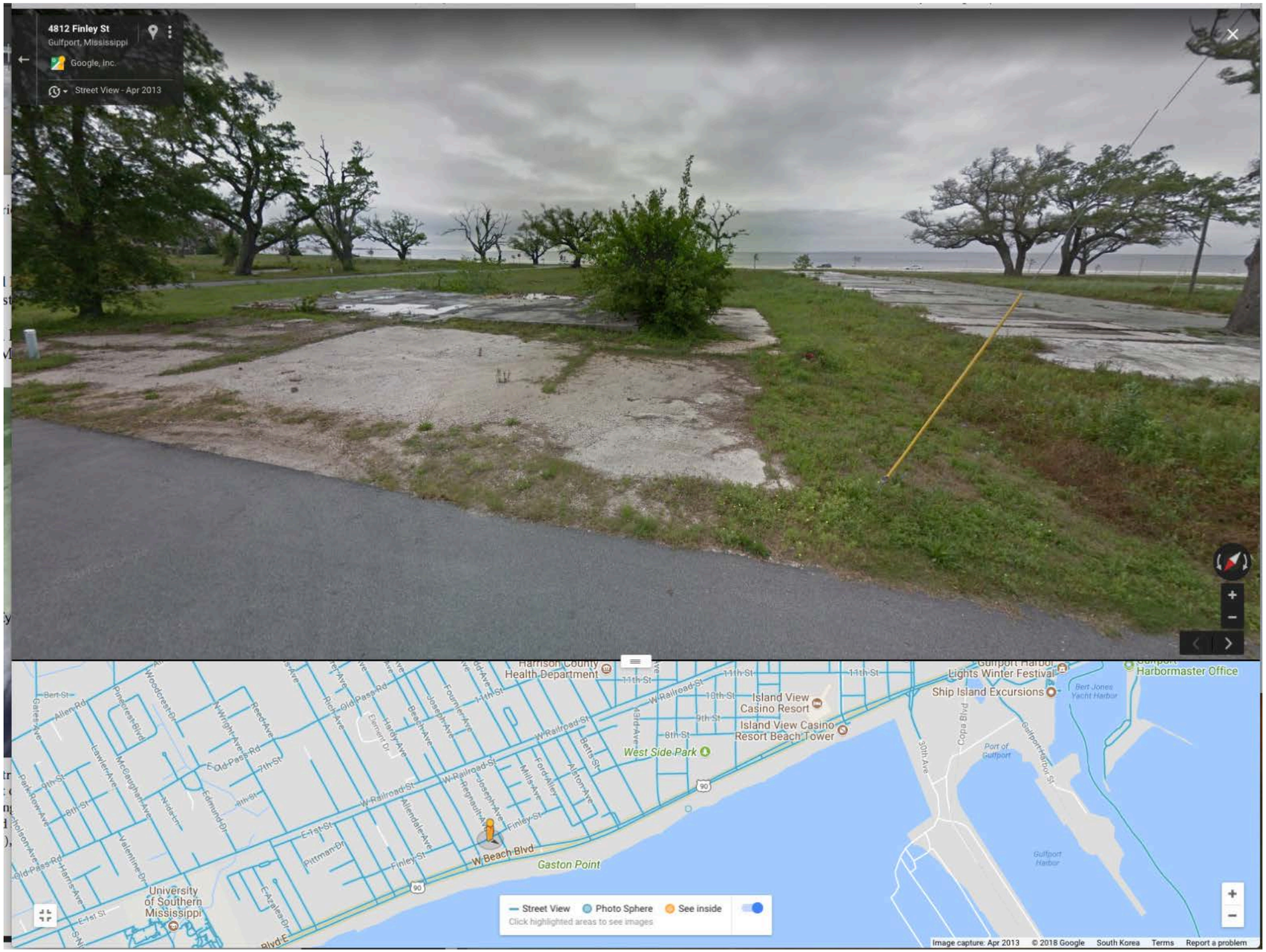
Hurricane Katrina, 2005

Hurricane Katrina, 2005

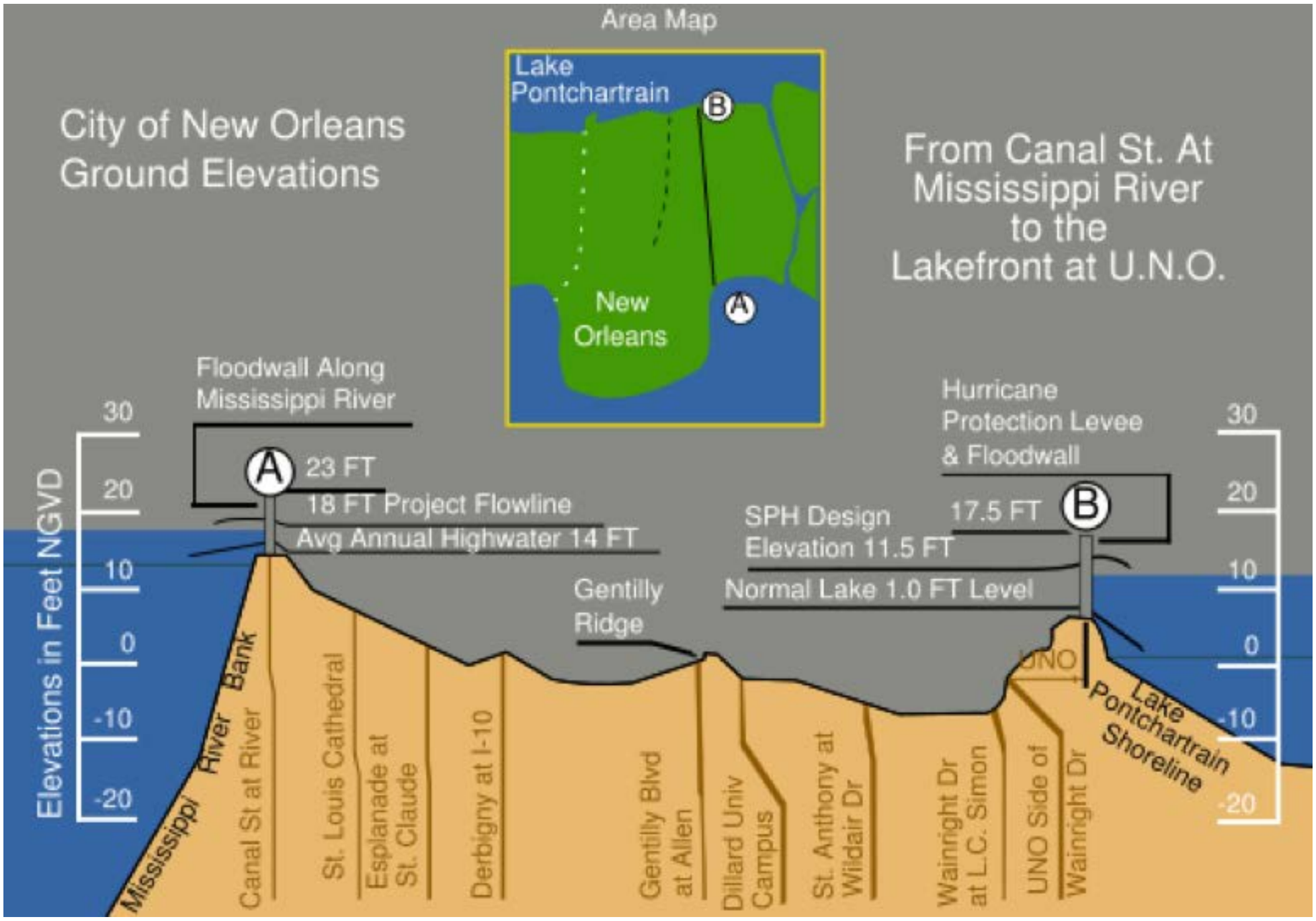




April, 2013, Gulfport, Mississippi



Hurricane Katrina, 2005



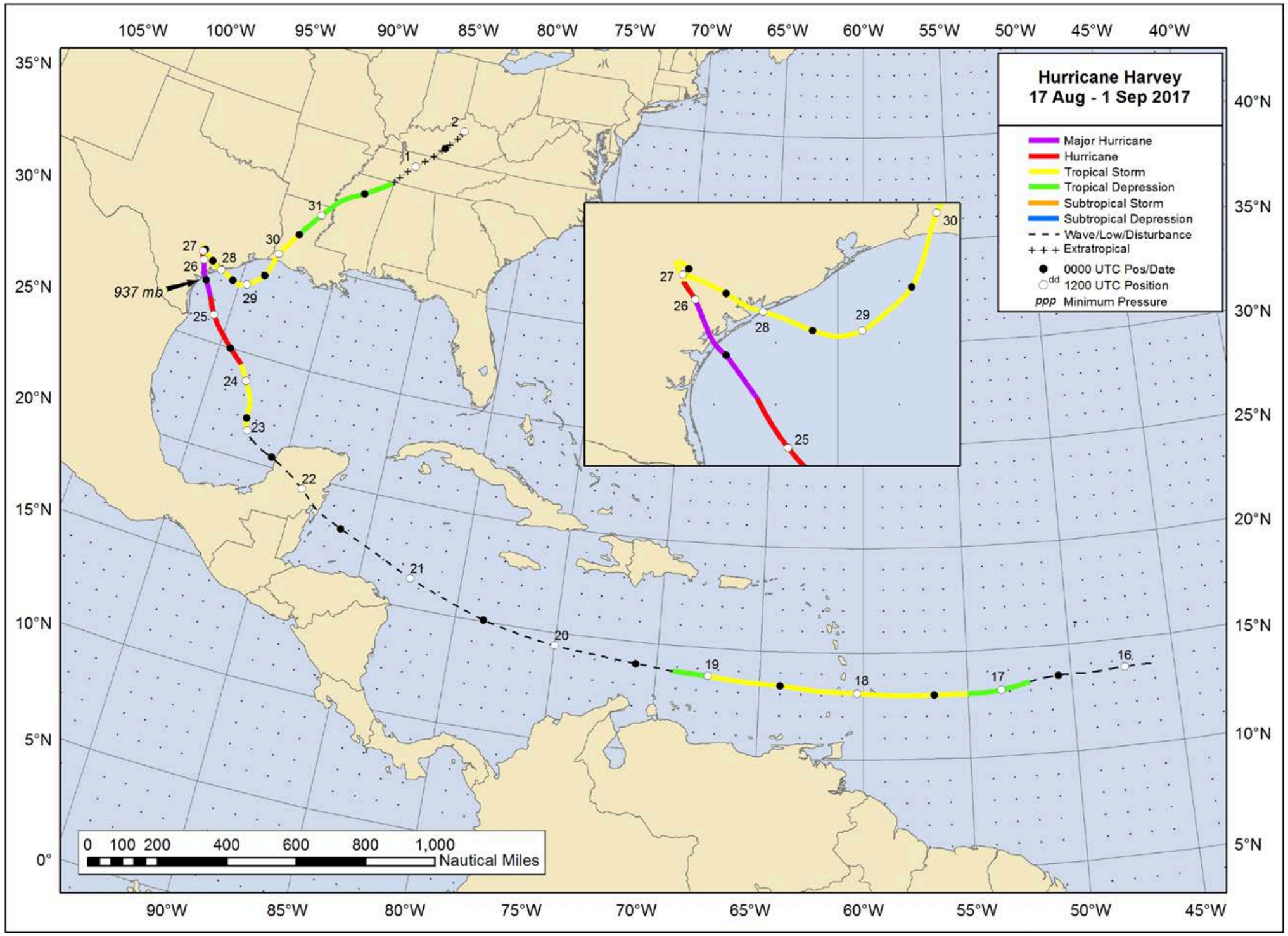
Hurricane Katrina, 2005

Flood waters inundate New Orleans, Louisiana, during August, 2005, after the winds and storm surge from Hurricane Katrina caused several levee breaks.

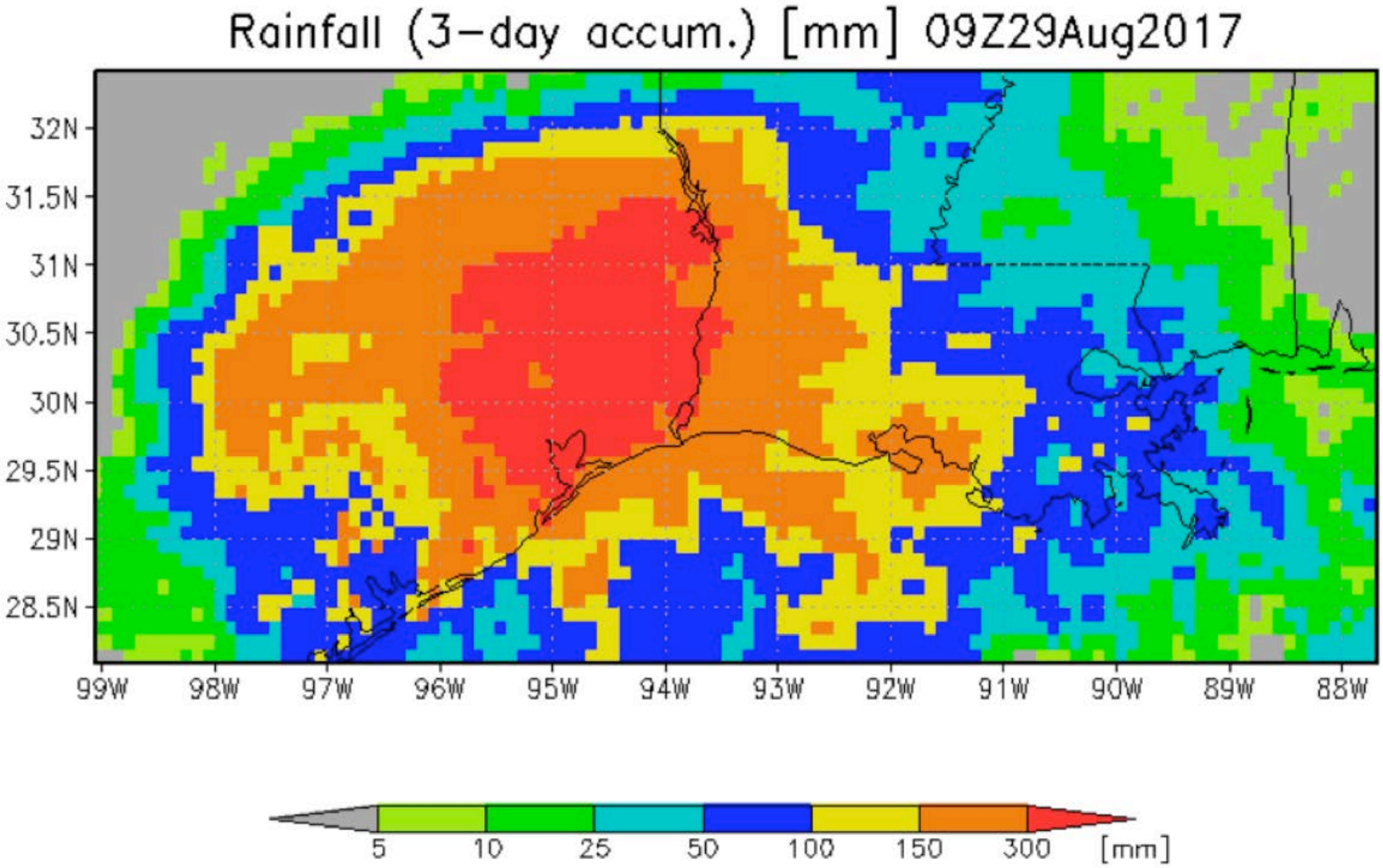
Hurricane Harvey, 2017

Astronaut Randy Bresnik took this photo of Tropical Storm Harvey from the International Space Station on Aug. 28 at 1:27 p.m. CDT

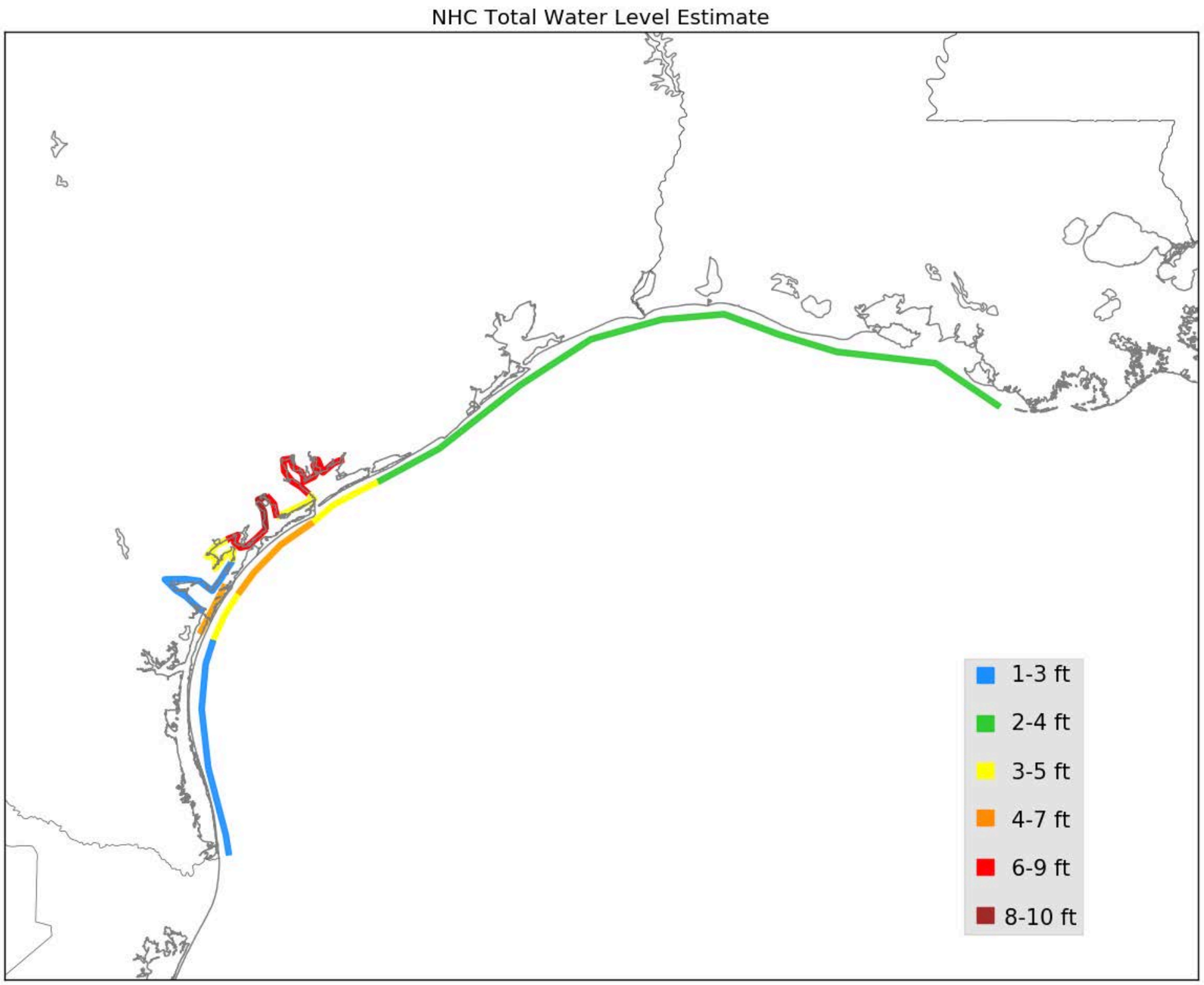
Hurricane Harvey, 2017



Hurricane Harvey, 2017



Hurricane Harvey, 2017



Hurricane Harvey, 2017

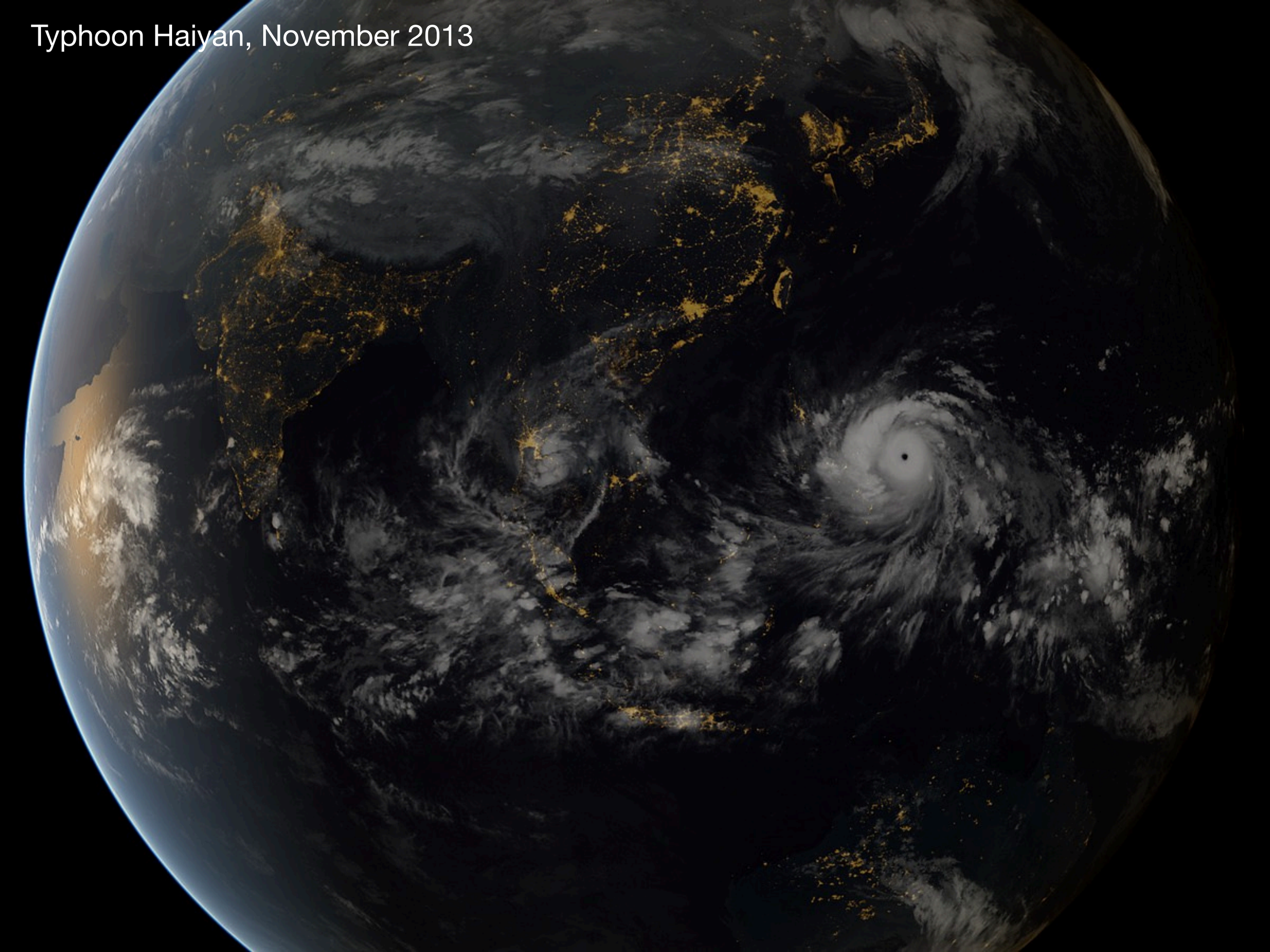
An example of the water rescues that were ongoing during Harvey in Houston on 27 August 2017. Photo credit David J. Phillip

Hurricane Harvey, 2017

Texas World Speedway after Harvey being used to store flooded cars.
Photo credit Brazos Drones.

Hurricane Harvey, 2017

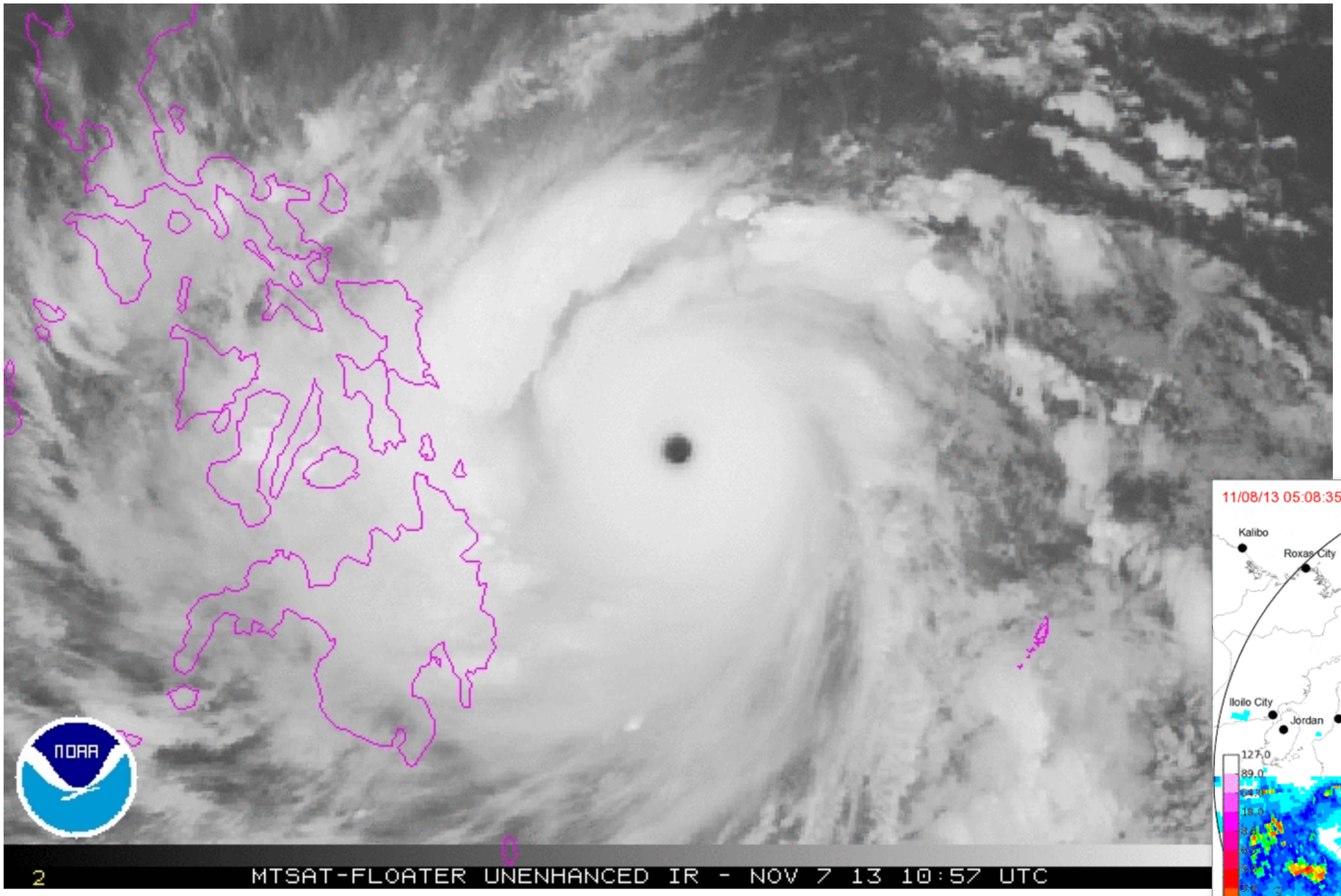
https://youtu.be/T0tcrzO83Mg

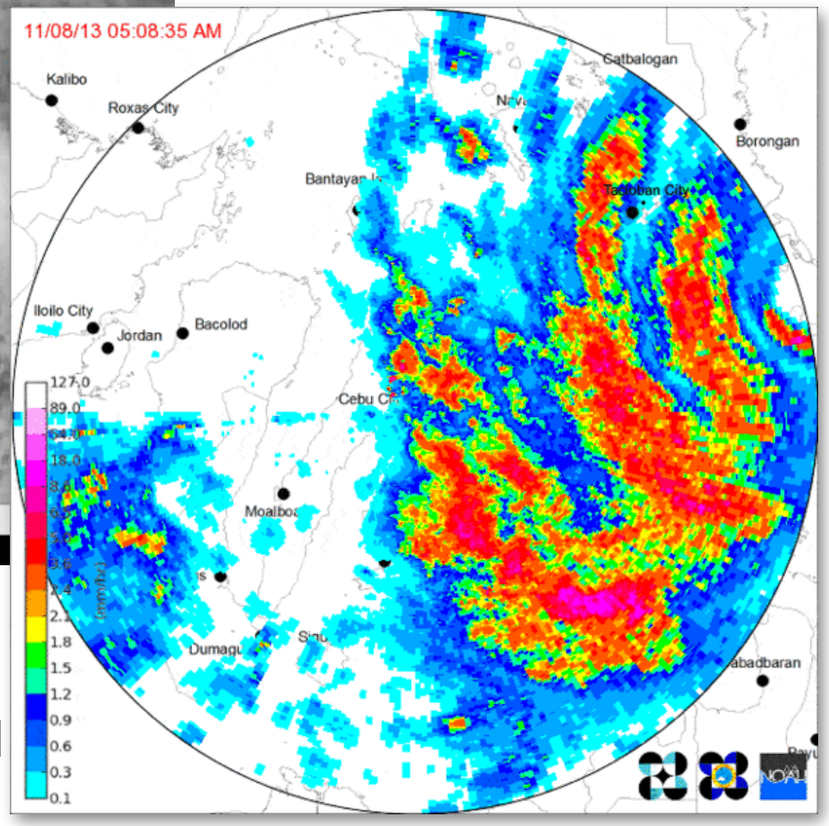

Typhoon Haiyan, November 2013

Typhoon Haiyan, 2013

- The system was generated on Nov. 2, 2013.
- Became category 5-equivalent typhoon on Nov. 5, 2013.
- On Nov. 7, the wind speeds were faster than 315 km/h with the minimum pressure of 895 mb.

Typhoon Haiyan, 2013





http://www.ospo.noaa.gov/Organization/History/imagery/Haiyan/index.html

Typhoon Haiyan, 2013

Country	Deaths	Missing
Philippines	6300	1061
Vietnam	13	4
China	8	9
Taiwan	8	0
Total	6329	1074

Basey, Samar

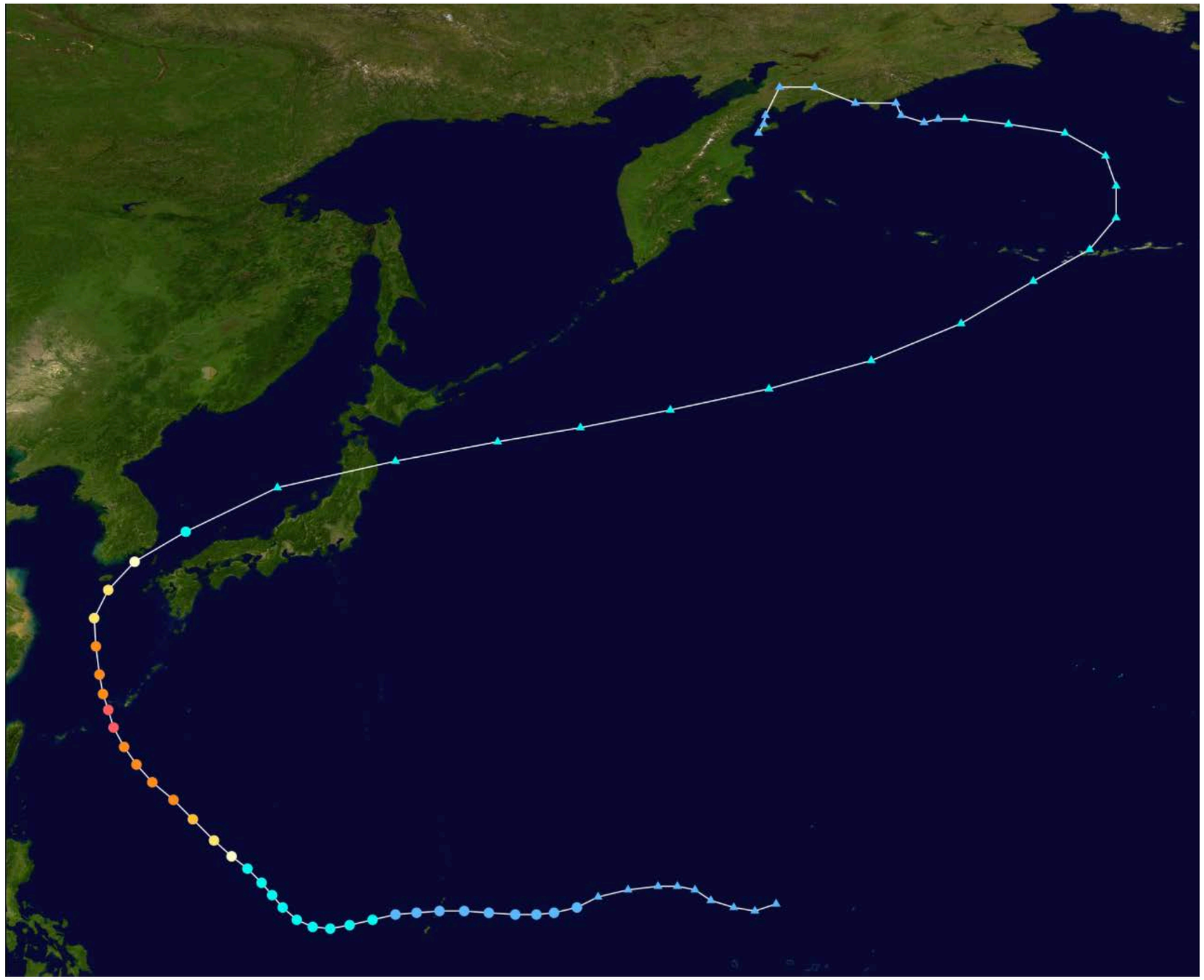
From: https://en.wikipedia.org/wiki/Typhoon_Haiyan

Super Typhoon Chaba, 2016

- Chaba intensified into a super typhoon (category 4) on October 3.
- Maximum wave heights reached 36 feet (10 meters) late on the following day.

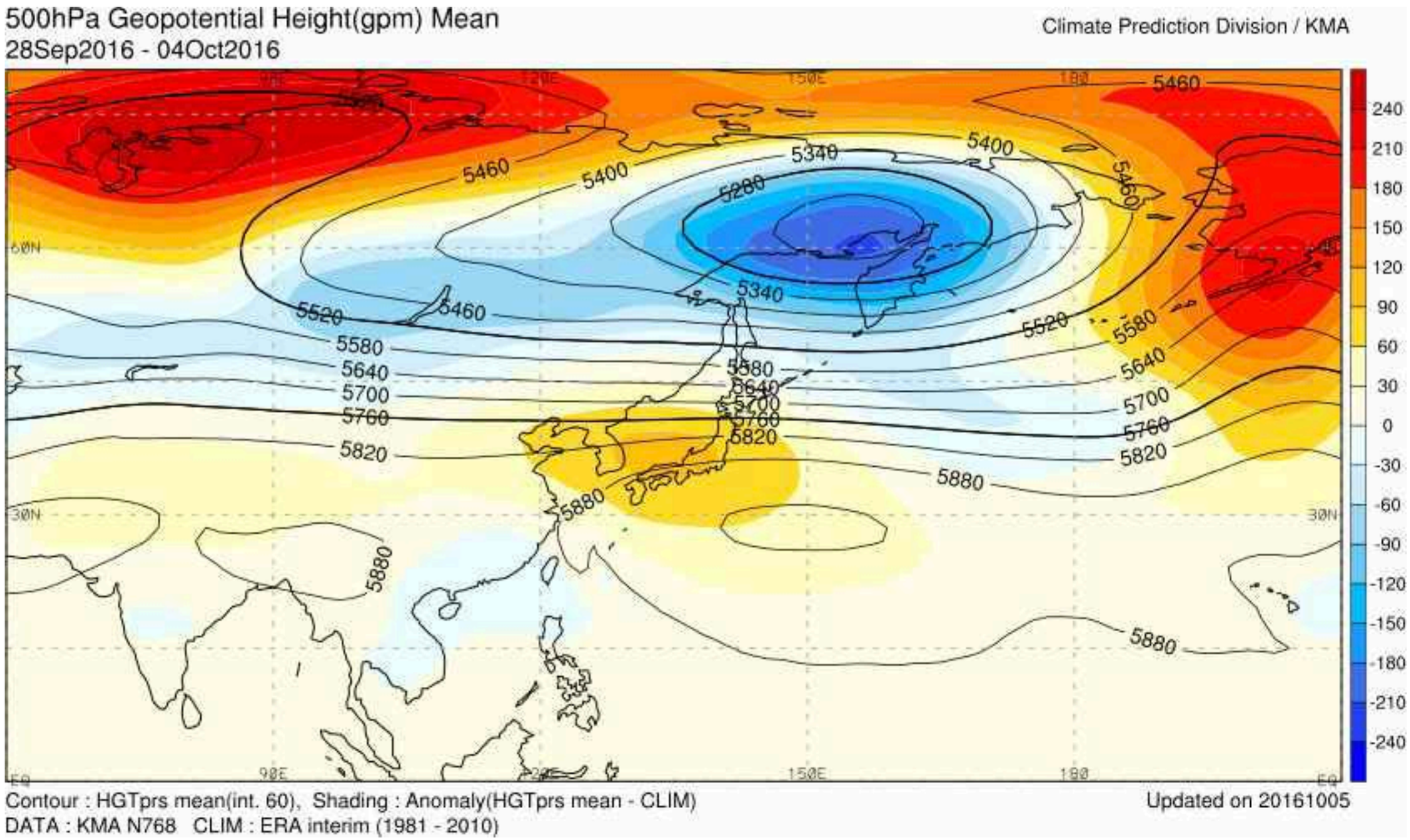
October 4, 2016 from MODIS satellite

Super Typhoon Chaba, 2016

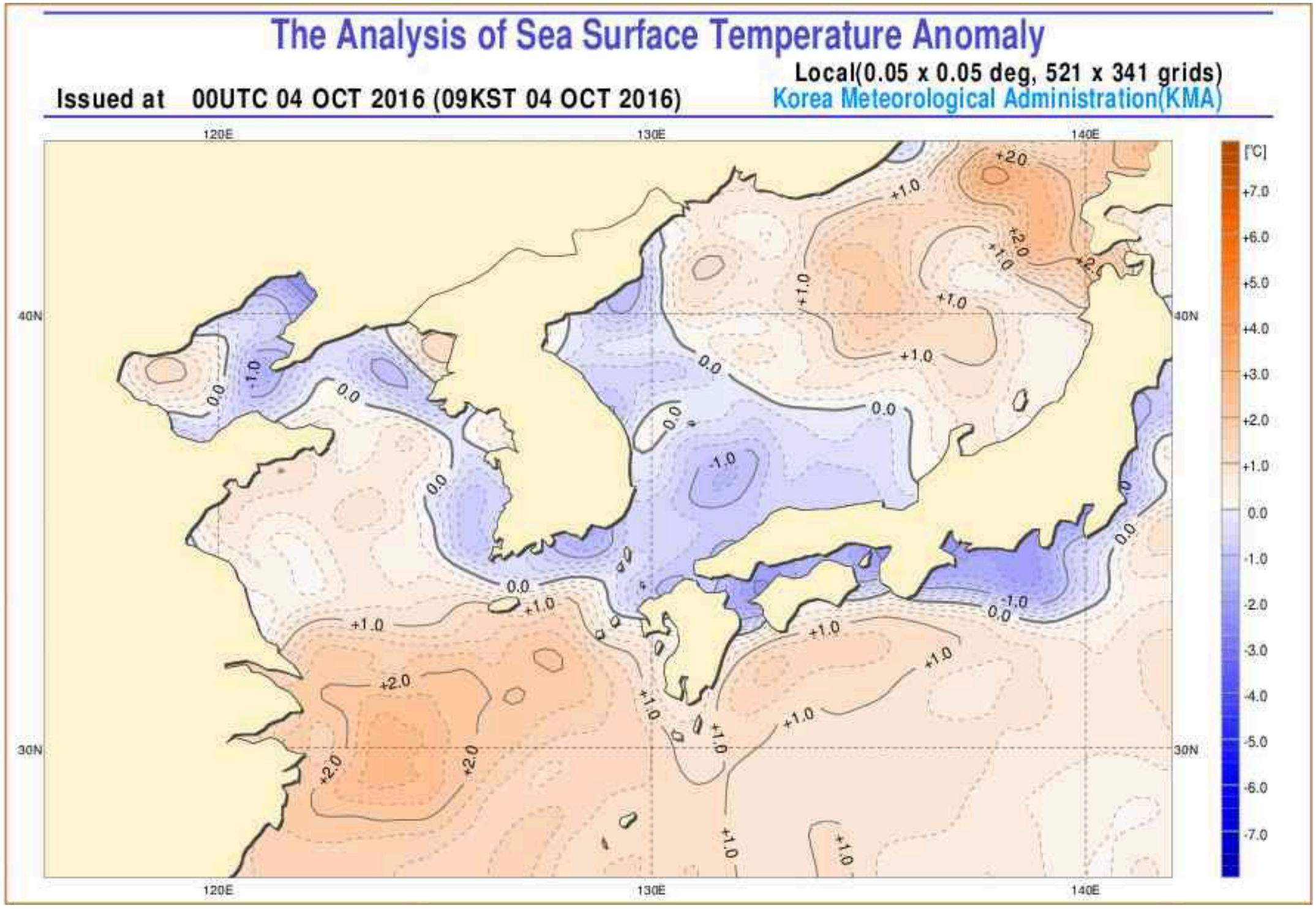


The points shows the location of the storm at every 6 hours.

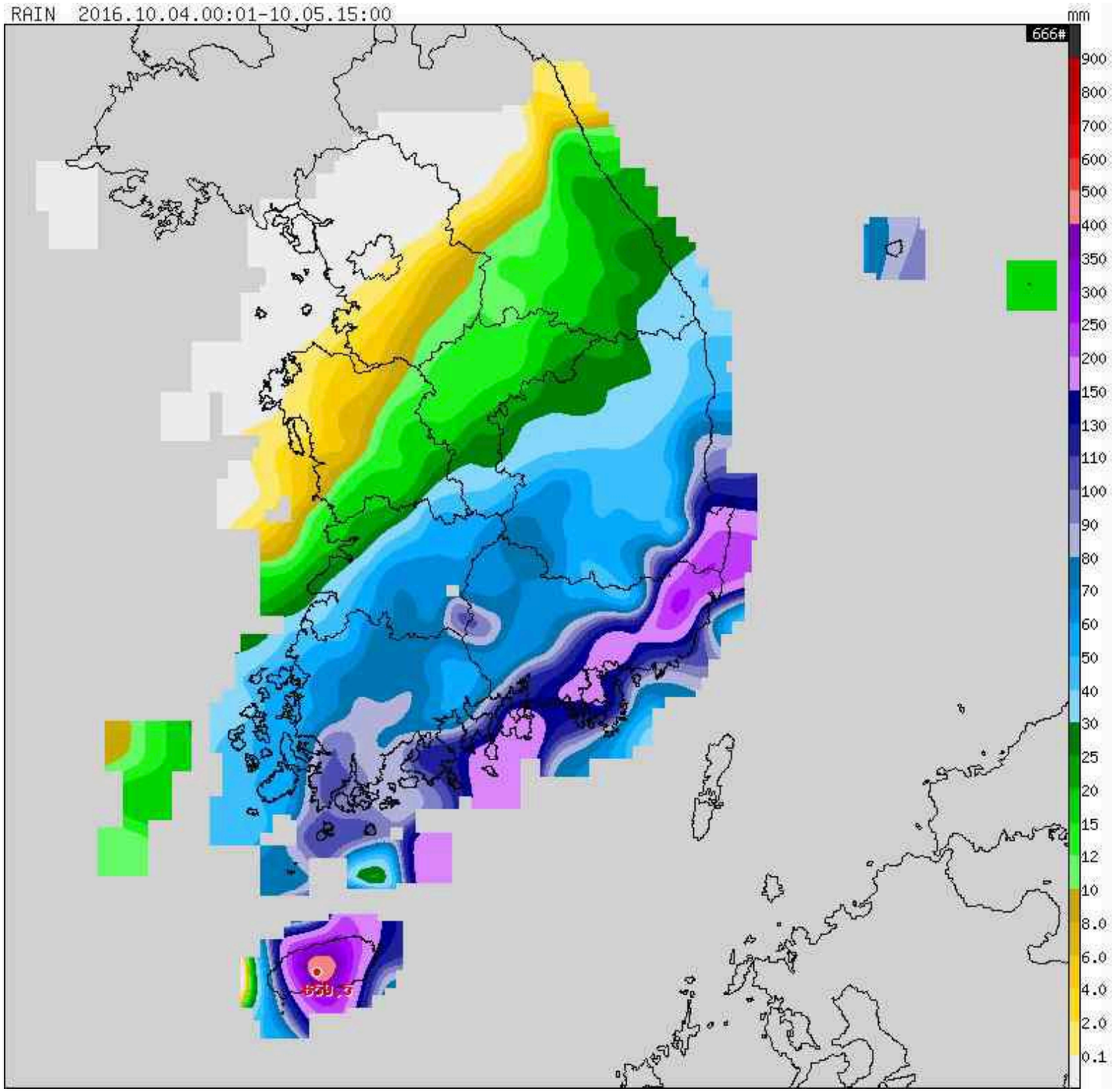
Super Typhoon Chaba, 2016



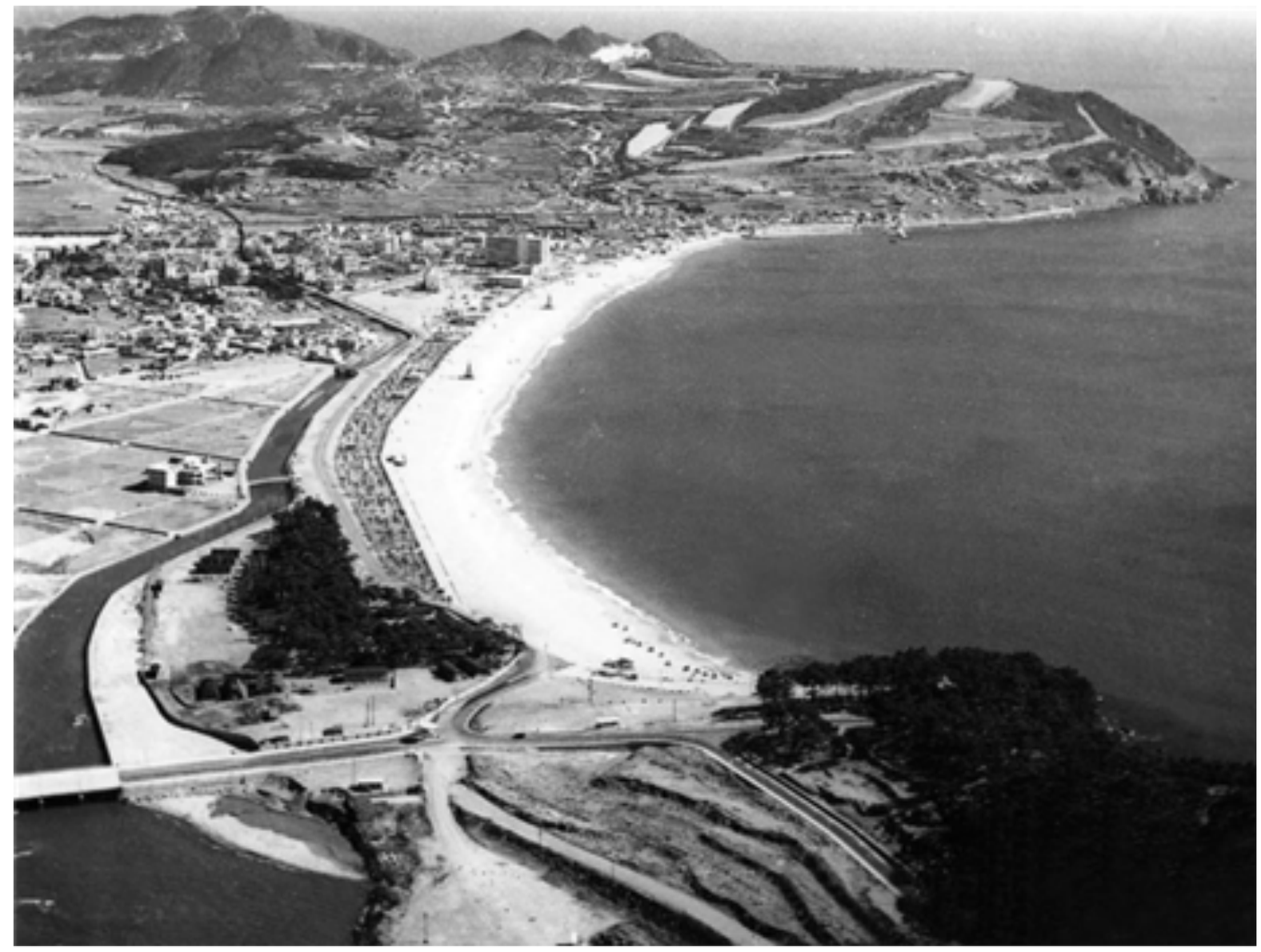
Sea surface temperature anomaly, Oct 04, 2016



Precipitation by typhoon Chaba

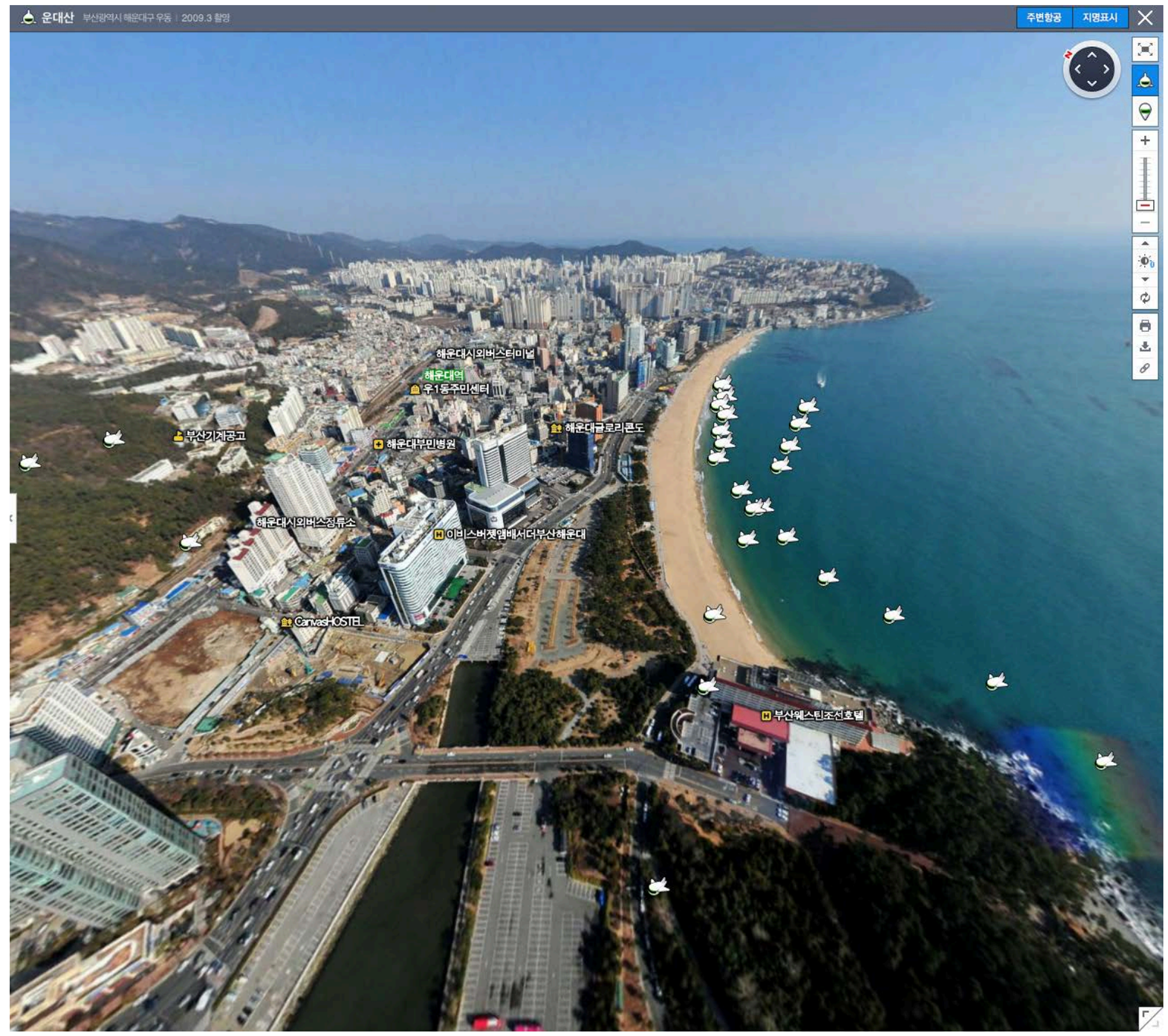


Haeundae in 1960, Busan



http://www.asiae.co.kr/news/view.htm?idxno=2017060110503569138

해운대 in 2009, Busan



Naver map

해운대 in 2009, Busan

Naver map

Vulnerability in Busan, South Korea

- video
- Number of typhoons that affected South Korea (1904-2010)

Year	1	2	3	4	5	6	7	8	9	10	11	12	Mean
#	-	-	-	-	2	20	97	126	84	9	-	-	3.1

- Insurance company investigating possible damages from typhoons (http://www.air-worldwide.com/Publications/AIR-Currents/2010/Managing-Typhoon-Risk-in-South-Korea/)