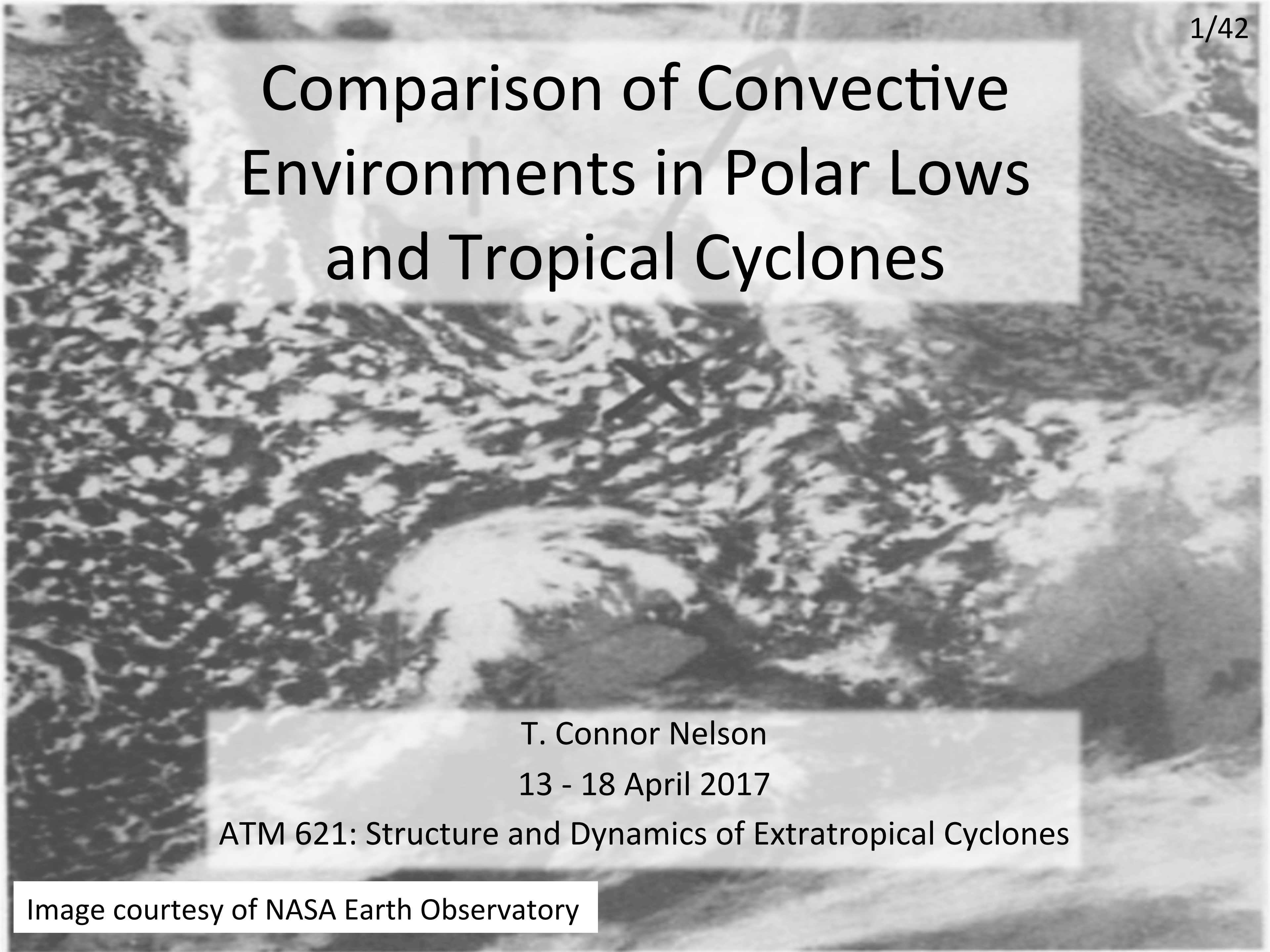


Comparison of Convective Environments in Polar Lows and Tropical Cyclones

T. Connor Nelson

13 - 18 April 2017

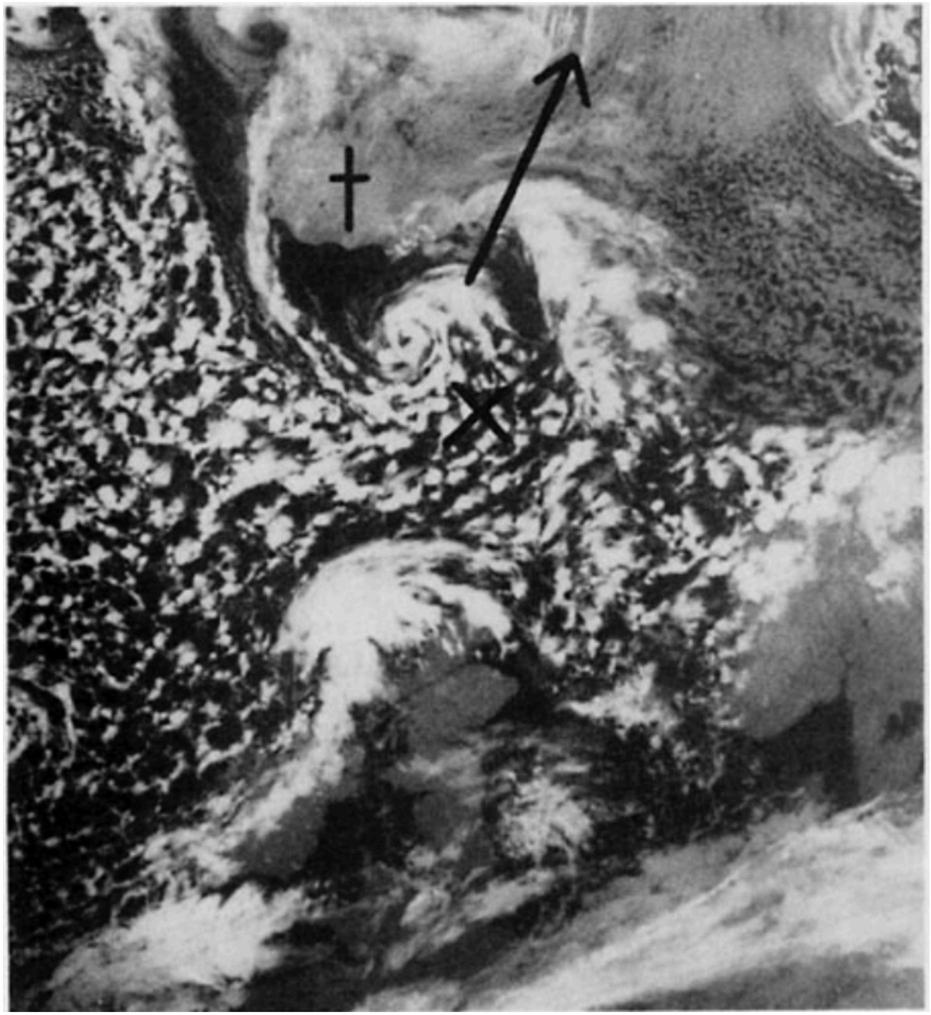
ATM 621: Structure and Dynamics of Extratropical Cyclones

Image courtesy of NASA Earth Observatory

Definitions…

- **Polar Low:**
  - Intense maritime cyclone
  - Forms poleward of the Polar Jet
  - Horizontal scale 10’s to 100’s km (AMS Glossary)
  - Low-level warm core
  - Surface winds approach gale force
    - 15 − 30 m s^{-1}

(Douglas et al. 1991; Montgomery and Farrell 1992; Moore and Haar 2003, Rasmussen and Turner 2003)



Definitions…

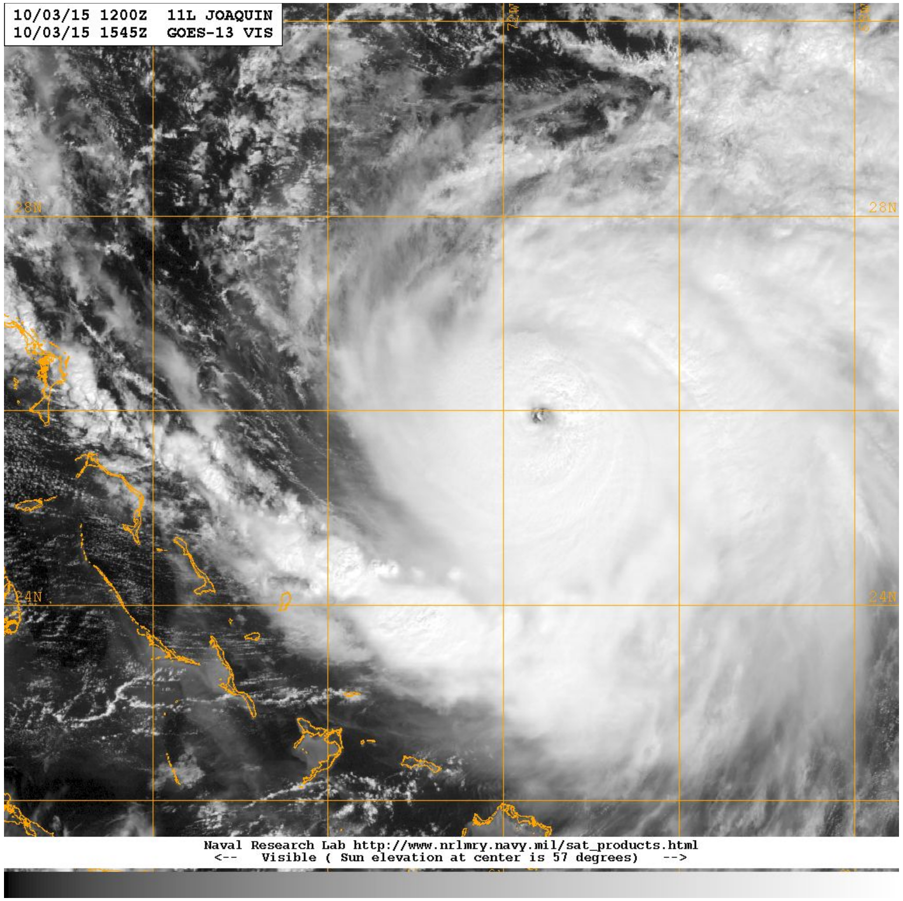


Image courtesy of the Naval Research Laboratory archives at http://www.nrlmry.navy.mil/TC.html

- **Tropical Cyclone:**
  - Intense maritime cyclone
  - Forms over tropics/ subtropics
  - Horizontal scale (500 – 1000 km)
  - Warm-core, non-frontal
  - Organized deep convection
  - Closed surface wind circulation
    - 17 – 70 m s^{-1}

(Adapted from National Hurricane Center 2016)

Definitions…

- **Polar Low (PL):**
  - Intense maritime cyclone
  - Forms poleward of the Polar Jet
  - Horizontal scale 10's to 100's km(AMS Glossary)
  - Low-level warm core
  - Surface winds approach gale force
    - 15 − 30 m s^{-1}

(Douglas et al. 1991; Montgomery and Farrell 1992; Moore and Haar 2003, Rasmussen and Turner 2003)

- **Tropical Cyclone (TC):**
  - Intense maritime cyclone
  - Forms over tropics/ subtropics
  - Horizontal scale (500 − 1000 km)
  - Warm-core, non-frontal
  - Organized deep convection
  - Closed surface wind circulation
    - 17 − 70 m s^{-1}

(Adapted from National Hurricane Center 2016)

Definitions…

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  - Intense maritime cyclone
  - Forms over tropics/
  - Organized deep convection
  - Closed surface wind circulation
    - 17 – 70 m s^{-1}

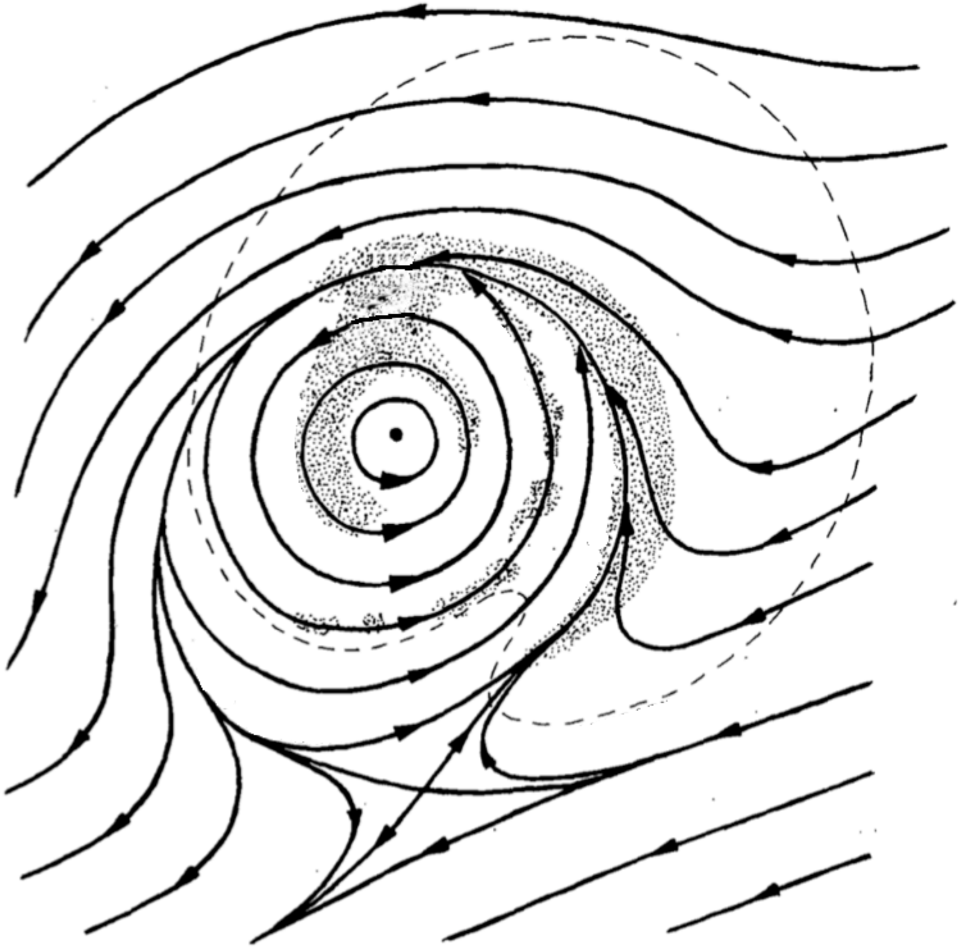
(Adapted from National Hurricane Center 2016)

Because of their similarities in appearance and structure, Emanuel and Rotunno (1989) called a subclass of Polar Lows ‘Arctic Hurricanes’.

Which One is a Polar Low?

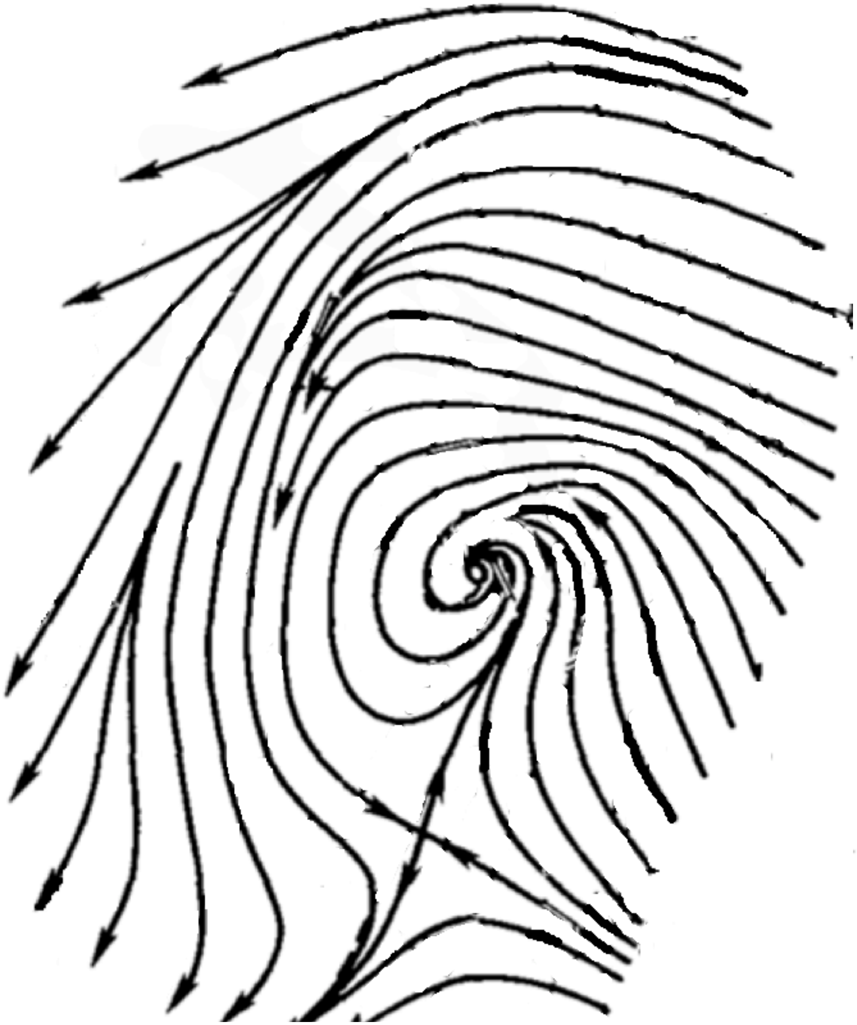
A

B



Polar Low

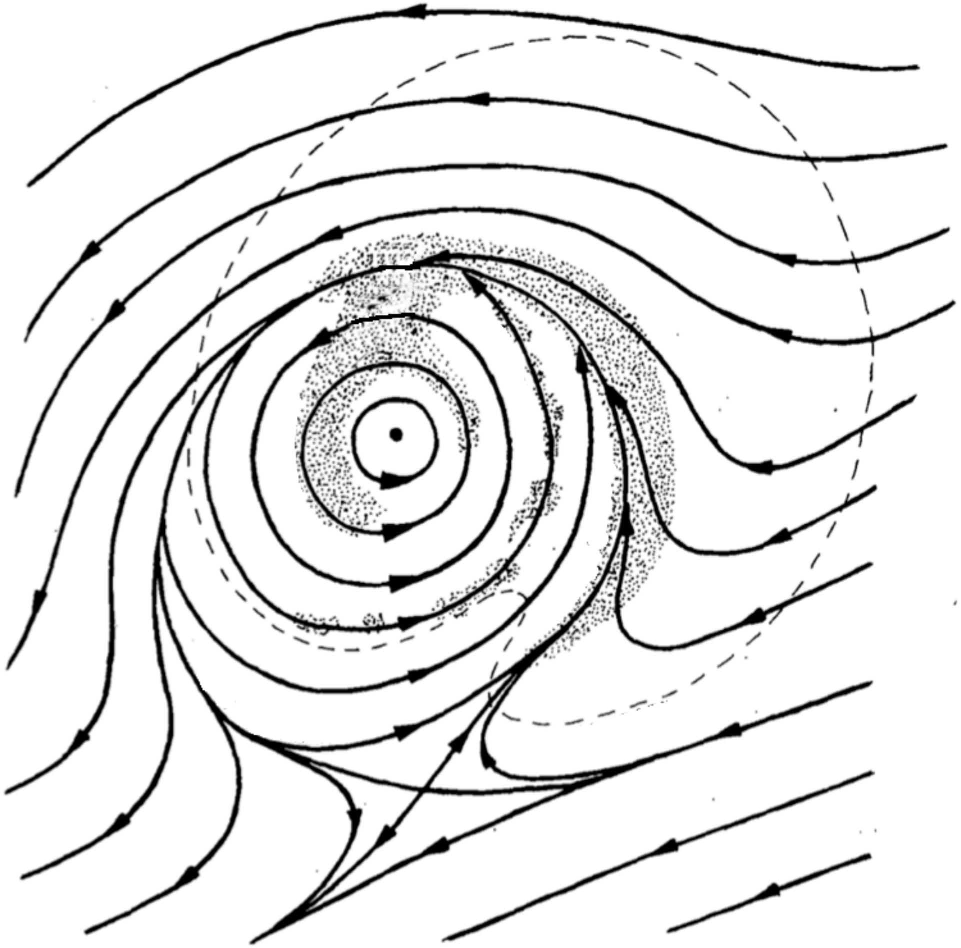
A



Douglas et al. 1991

Tropical Cyclone

B



Willoughby et al. 1984

Formation and Maintenance of PLs vs. TCs

- Tropical Cyclones
  - Pre-existing disturbance (e.g. African Easterly Wave, Chen et al. 2009)
  - Bottom-up theory (e.g., Hendricks et al. 2004)
  - Top-down theory (e.g., Bister and Emanuel 1997)
  - Barotropic instability (e.g., Schubert et al. 1999)
- Polar Lows
  - Pre-existing disturbance (e.g., mid-latitude cyclone)
  - Cold air outbreaks over warm ocean (e.g., Rasmussen 1981)
  - Interlocking PV maxima (e.g., Douglas et al. 1991)
  - CISK/WISHE (e.g., Emanuel and Rotunno 1989)
  - Baroclinic instability (e.g., Moore and Haar 2003)

Formation and Maintenance of PLs vs. TCs

- Tropical Cyclones
  - Pre-existing disturbance (e.g. African Easterly Wave, Chen et al. 2009)

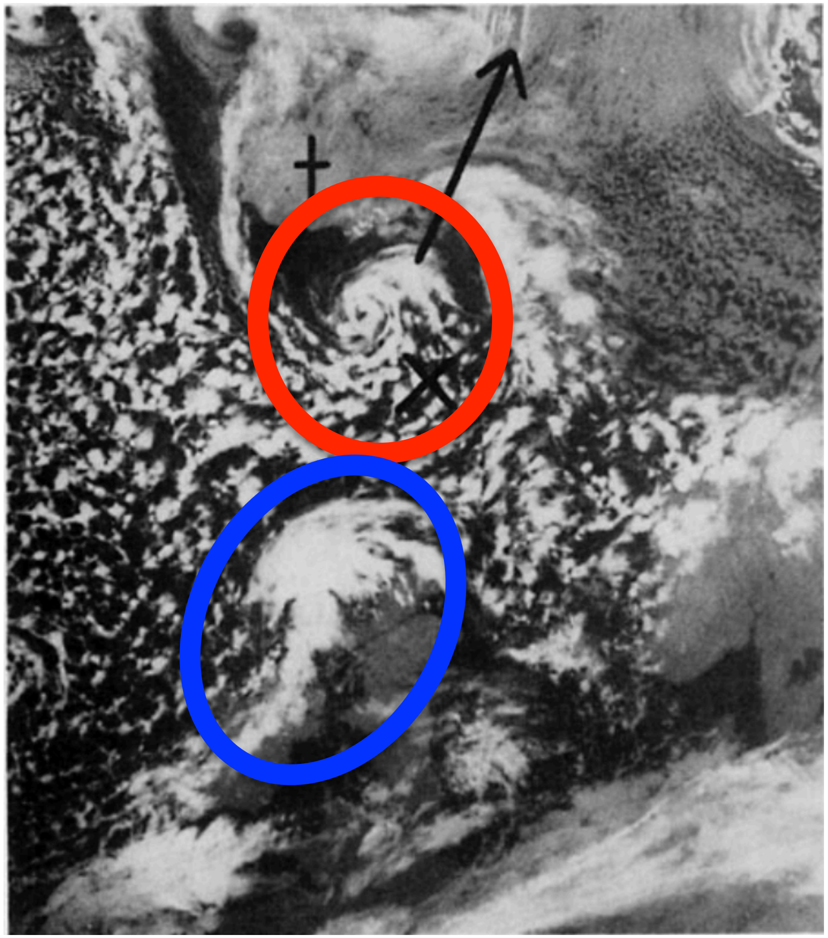
These similarities and differences help to dictate where deep convection occurs in different cyclones!

*We can, therefore, infer much about 'Arctic hurricanes' from observations of TCs…

  - CISK/WISHE (e.g., Emanuel and Rotunno 1989)
  - Baroclinic instability (e.g., Moore and Haar 2003)

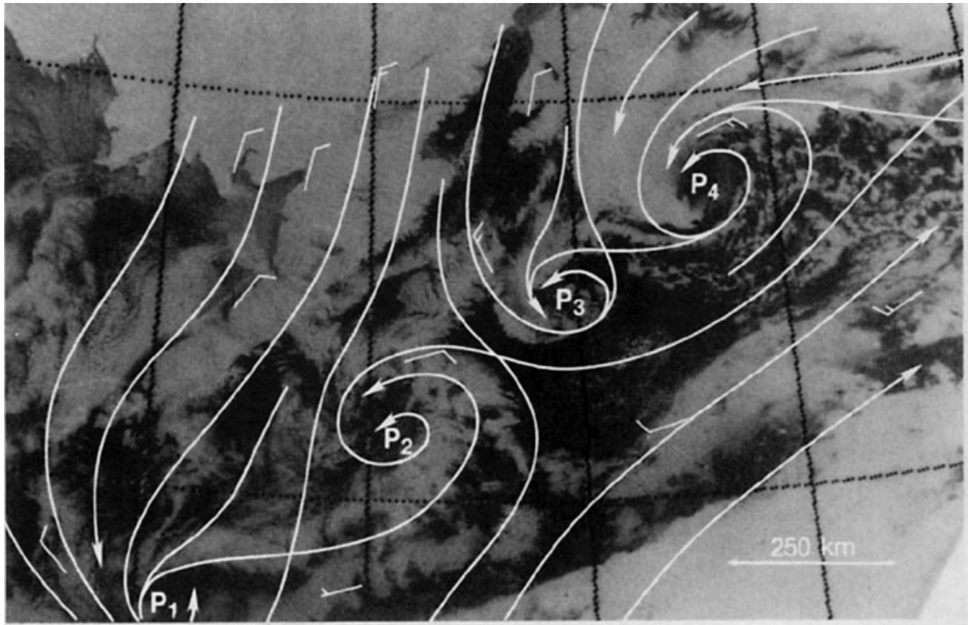
Two Main Archetypes for Polar Lows

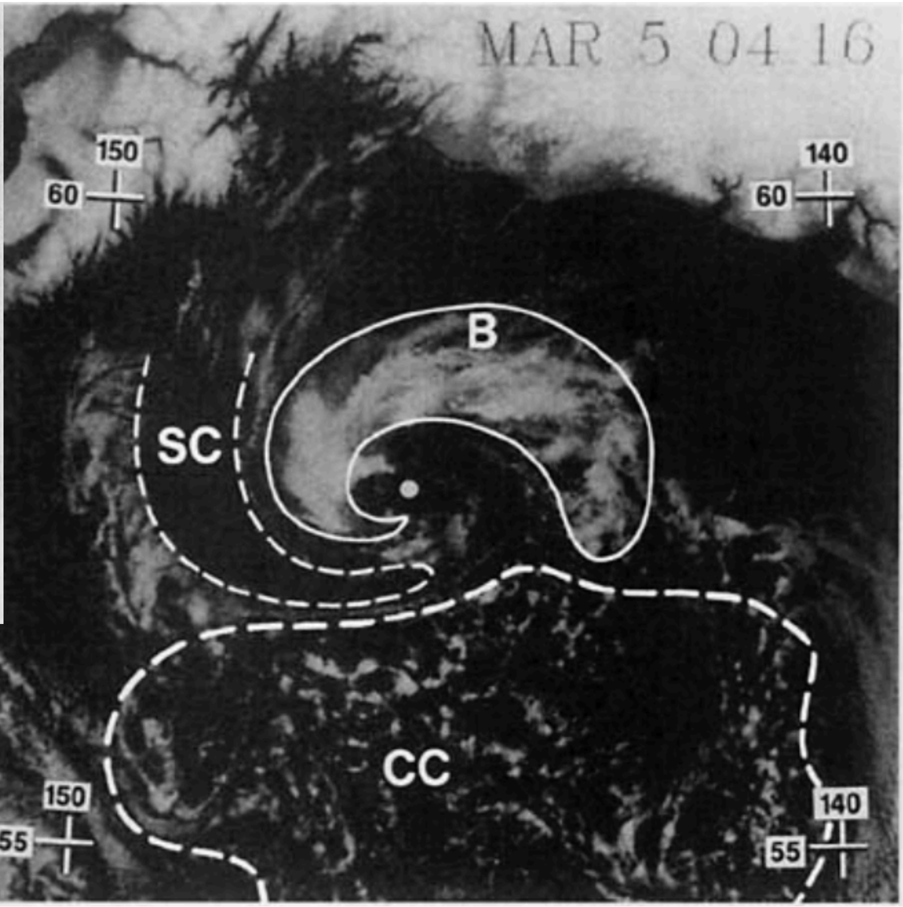
- **'Arctic hurricane' (AH):** tight circulation, well defined eye, convective "rainbands"
- **Classic 'comma cloud':** circulation with extending primary convective band



Adapted from Rasmussen 1981. His Fig.6

Regardless of Archetype…

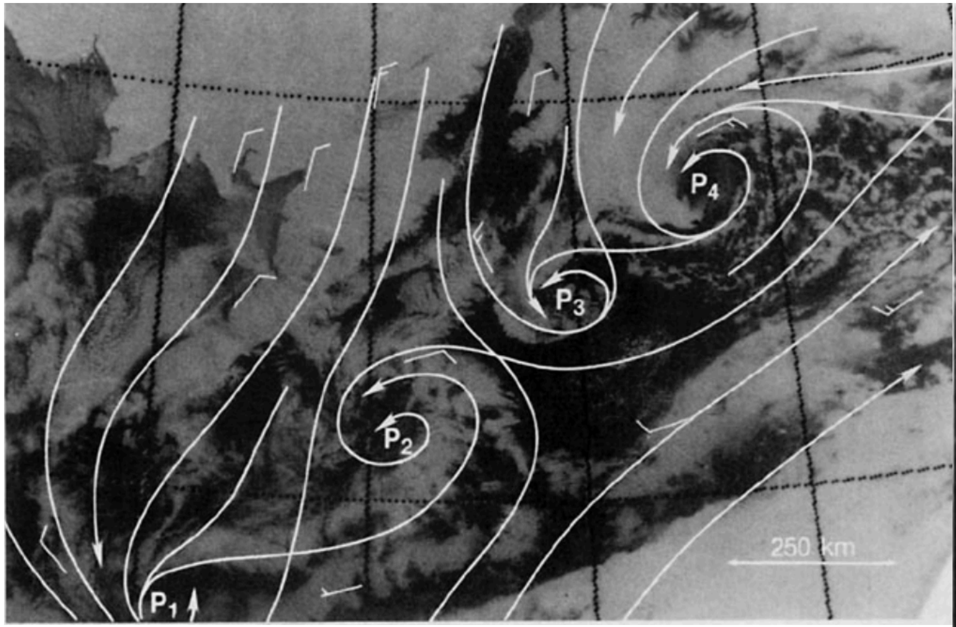


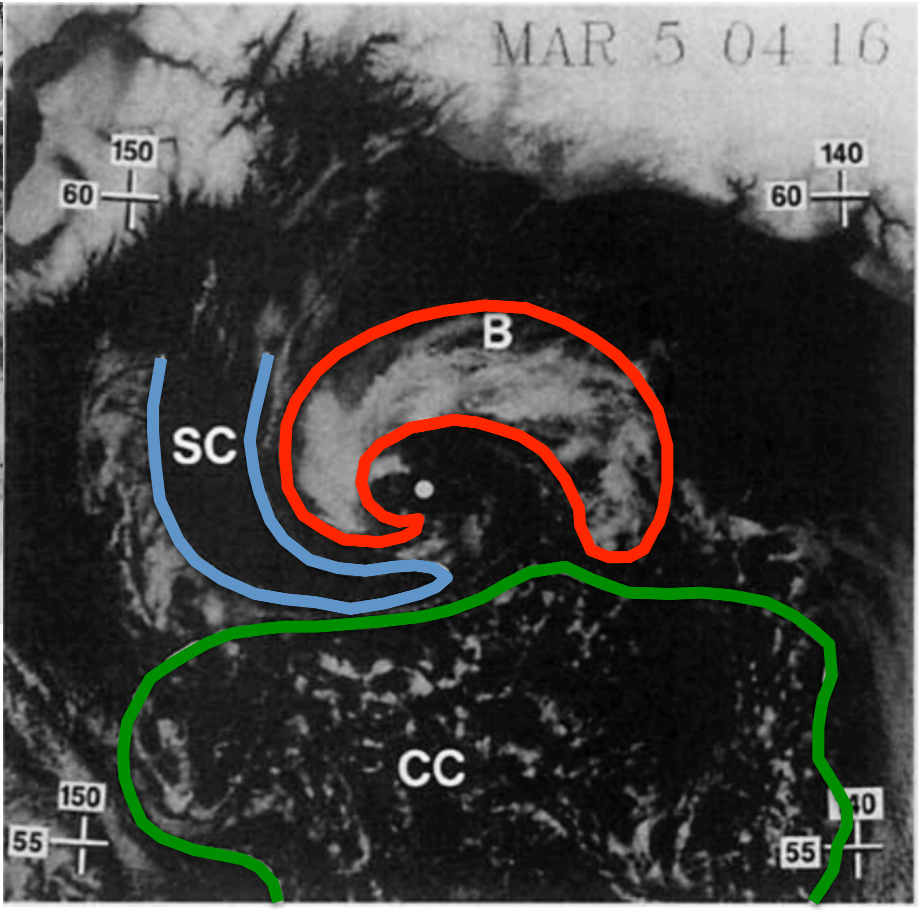


- PLs can occur as “lines” of waves

Adapted from Douglas et al. 1991

Regardless of Archetype…

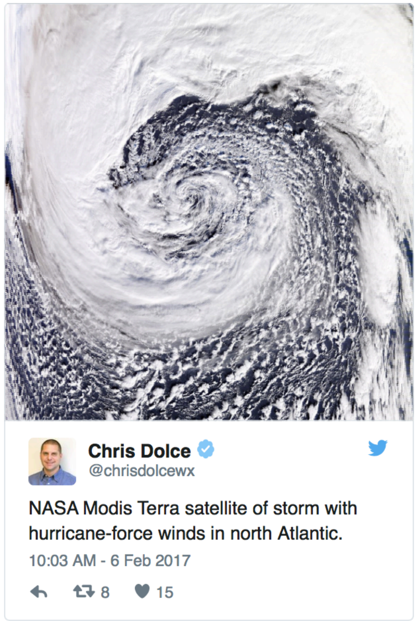




- Will have a primary band (B)
- Dry slot of suppressed convection (SC)
- Enhanced scattered convection (CC)

Adapted from Douglas et al. 1991

“Polar Lows” in the News?

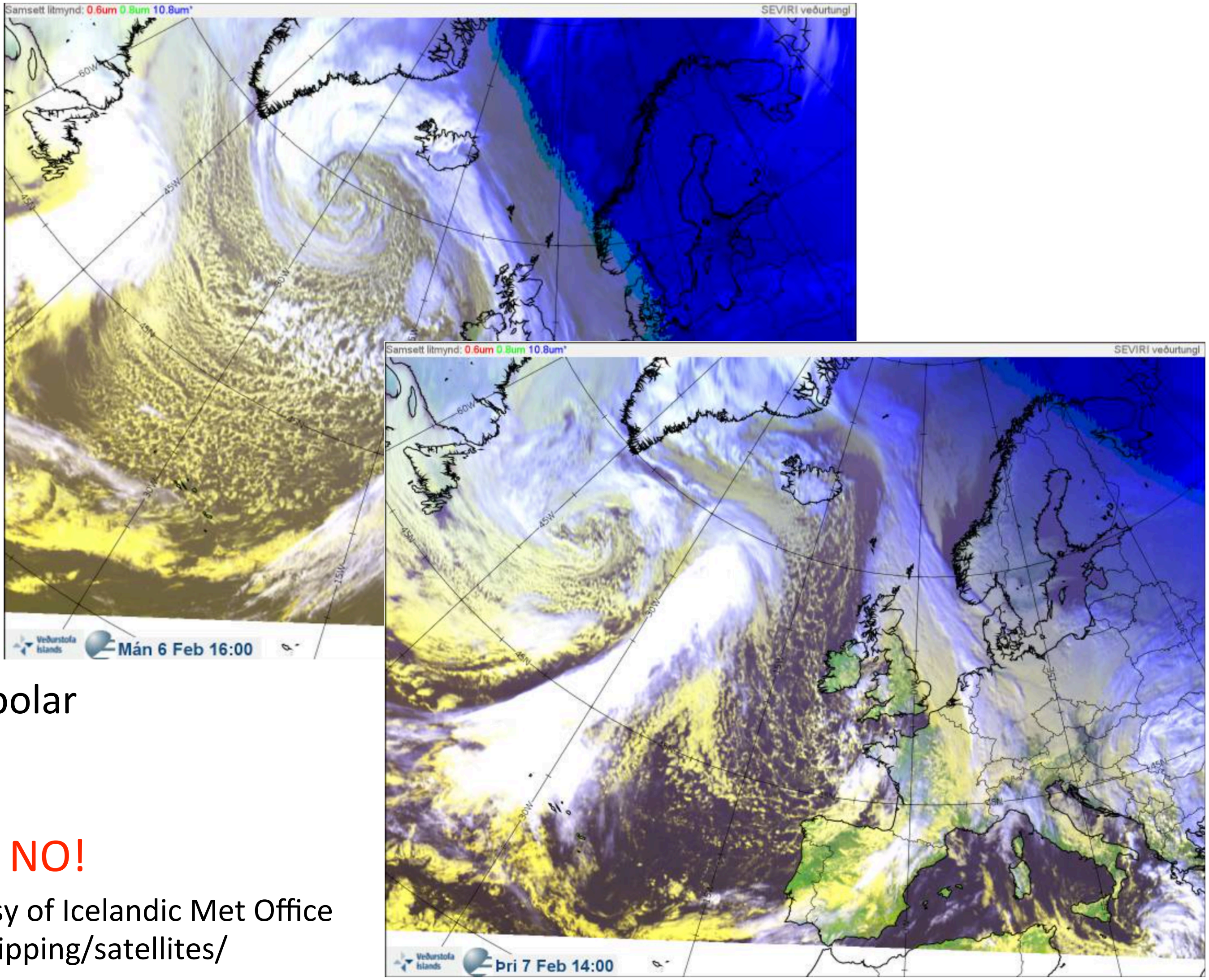


Chris Dolce
@chrisdolcewx

NASA Modis Terra satellite of storm with hurricane-force winds in north Atlantic.

10:03 AM - 6 Feb 2017

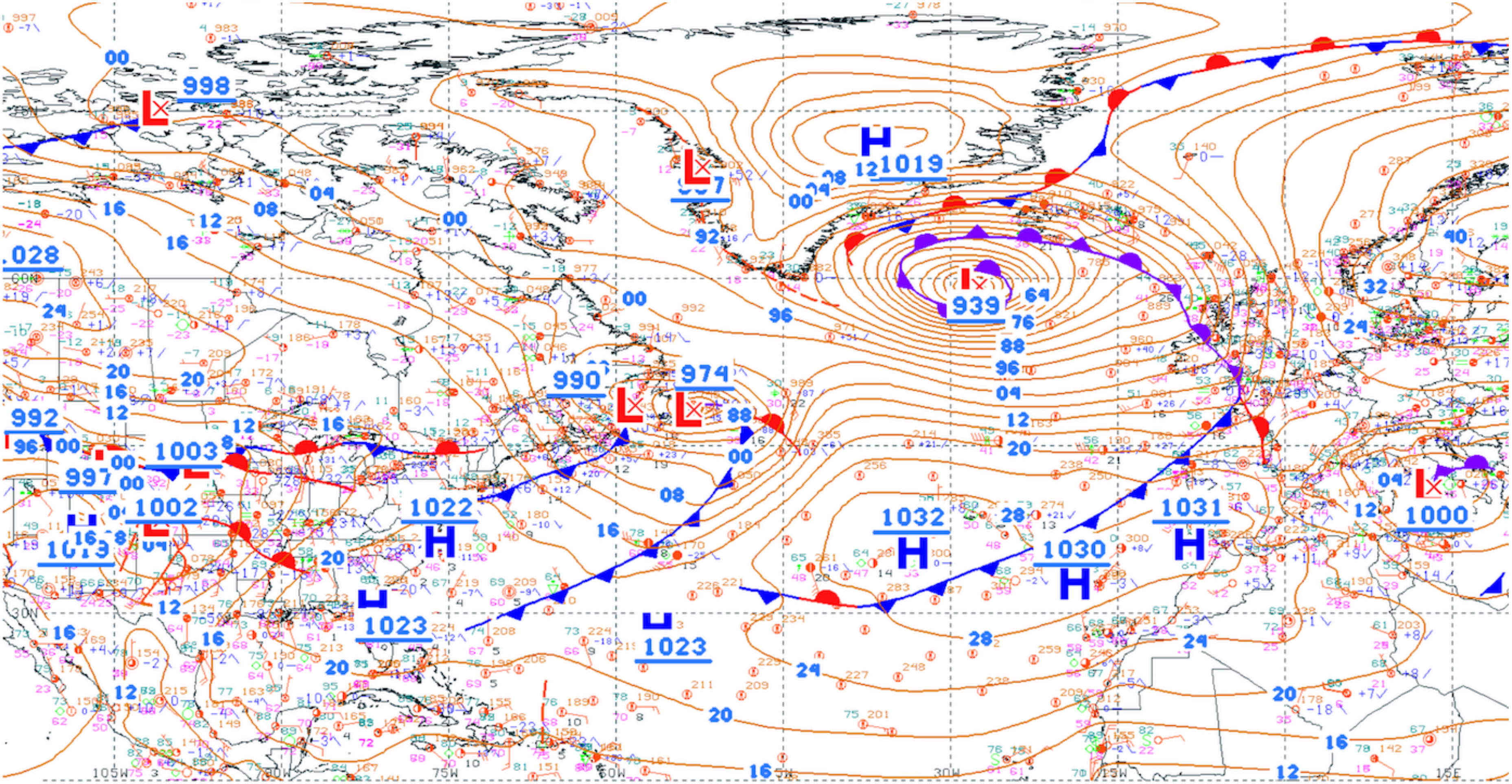
8 15



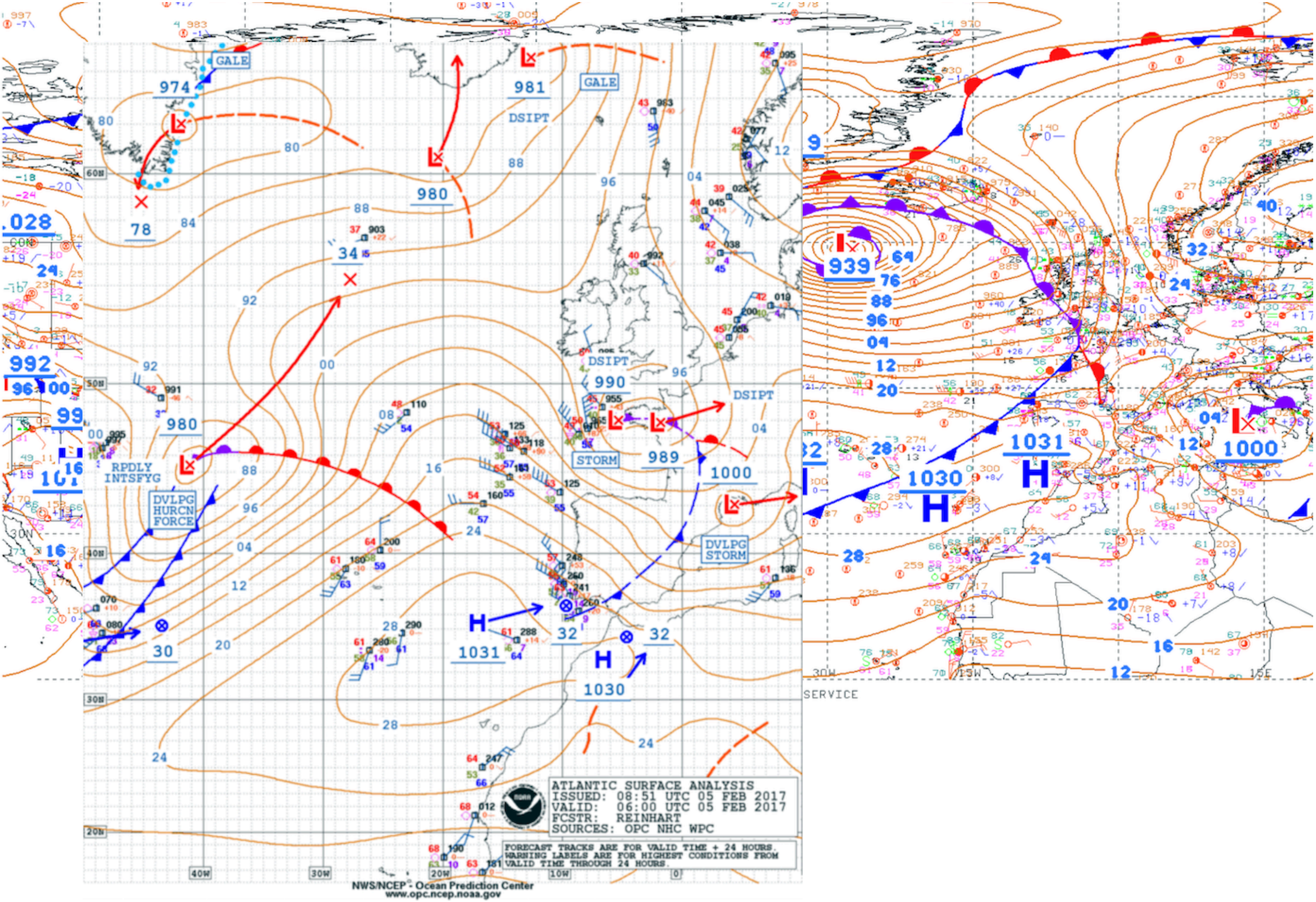
Does this constitute a polar low after fracture?

Group Discussion Says: NO!

Satellite images on left courtesy of Icelandic Met Office
http://en.vedur.is/weather/shipping/satellites/



18 UTC FEBRUARY 06 2017 - NATIONAL WEATHER SERVICE


ATLANTIC SURFACE ANALYSIS
ISSUED: 08:51 UTC 05 FEB 2017
VALID: 06:00 UTC 05 FEB 2017
FCSTR: REINHART
SOURCES: OPC NHC WPC
FORECAST TRACKS ARE FOR VALID TIME + 24 HOURS.
WARNING LABELS ARE FOR HIGHEST CONDITIONS FROM
VALID TIME THROUGH 24 HOURS.
NWS/NCEP Ocean Prediction Center
www.opc.ncep.noaa.gov
GALE
974
981
DSIPT
980
78
34
RPDLY INTSFYG
DVLPG HURCN FORCE
980
990
STORM
989
1000
DVLPG STORM
1031
1030
30
939
1031
1030
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Appreciate the Past

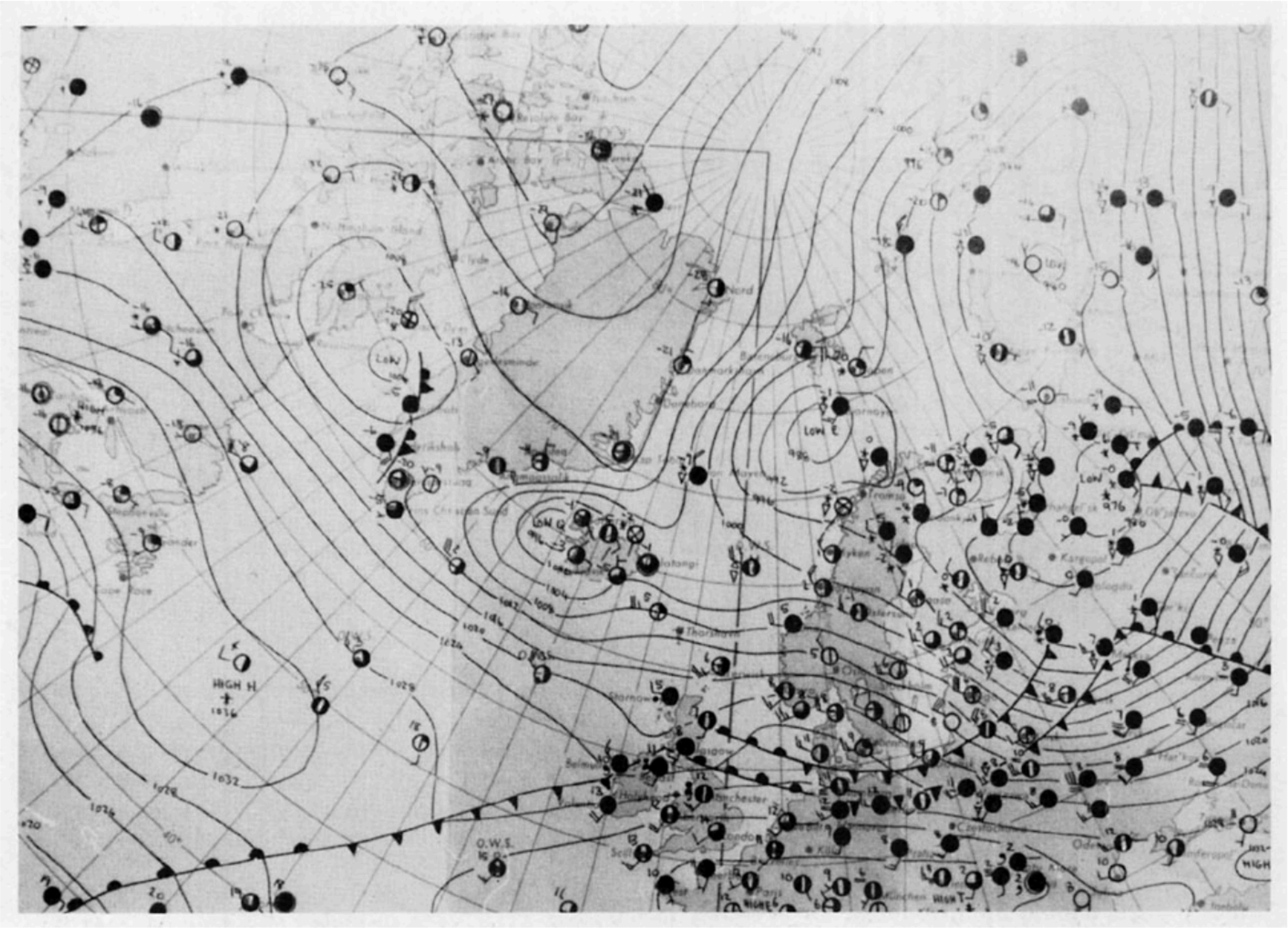
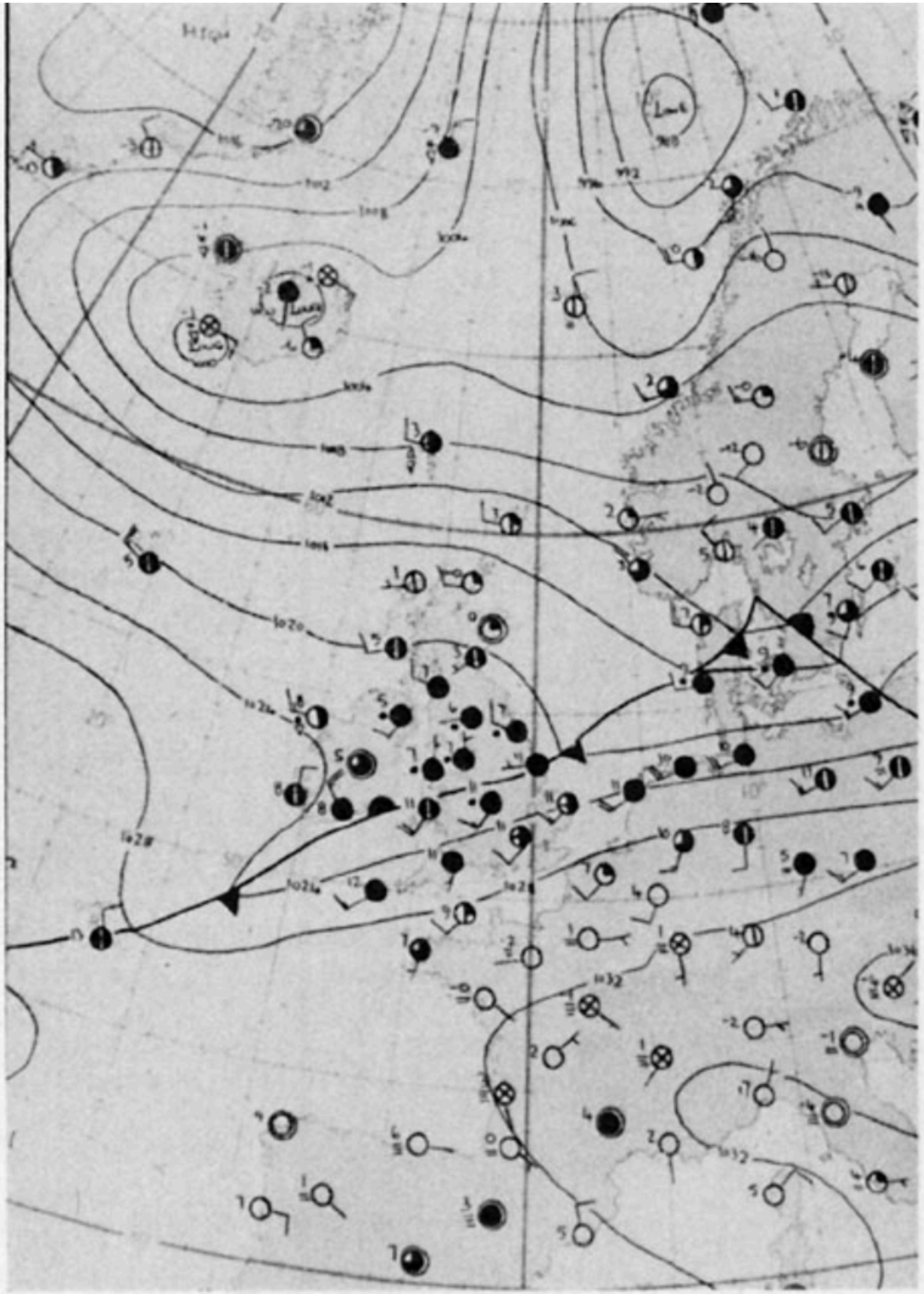


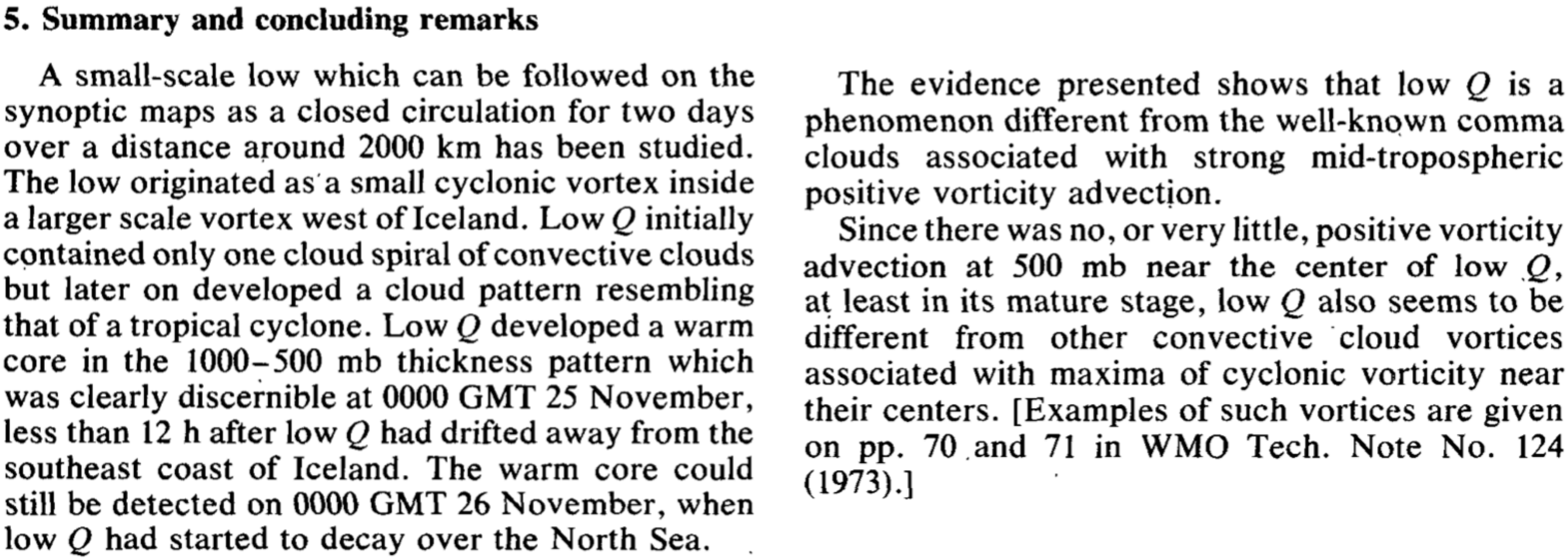
FIG. 1. Surface map 1200 GMT 23 November 1978. Reproduced from *Daily Weather Report of the British Meteorological Office.*

Rasmussen 1981



06 UTC 24 Nov 1978 [Left]
1932 UTC 24 Nov 1978 [Above]

Rasmussen 1981



5. Summary and concluding remarks

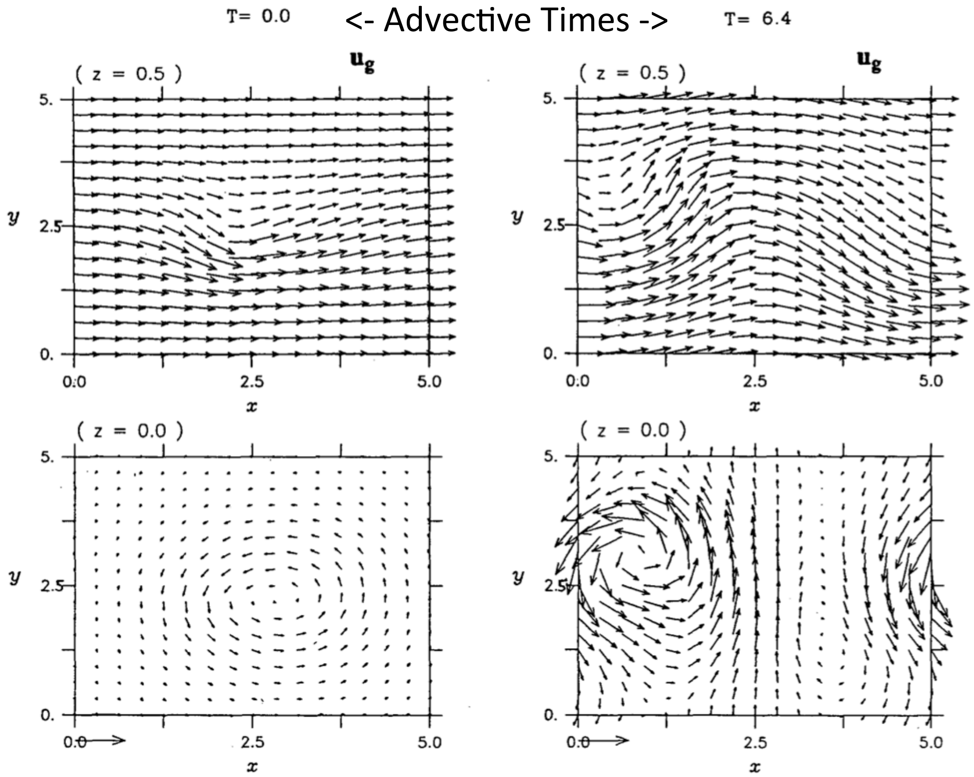
A small-scale low which can be followed on the synoptic maps as a closed circulation for two days over a distance around 2000 km has been studied. The low originated as a small cyclonic vortex inside a larger scale vortex west of Iceland. Low *Q* initially contained only one cloud spiral of convective clouds but later on developed a cloud pattern resembling that of a tropical cyclone. Low *Q* developed a warm core in the 1000–500 mb thickness pattern which was clearly discernible at 0000 GMT 25 November, less than 12 h after low *Q* had drifted away from the southeast coast of Iceland. The warm core could still be detected on 0000 GMT 26 November, when low *Q* had started to decay over the North Sea.

The evidence presented shows that low *Q* is a phenomenon different from the well-known comma clouds associated with strong mid-tropospheric positive vorticity advection.

Since there was no, or very little, positive vorticity advection at 500 mb near the center of low *Q*, at least in its mature stage, low *Q* also seems to be different from other convective cloud vortices associated with maxima of cyclonic vorticity near their centers. [Examples of such vortices are given on pp. 70 and 71 in WMO Tech. Note No. 124 (1973).]

PL Low-level Circulation

<- Advective Times ->

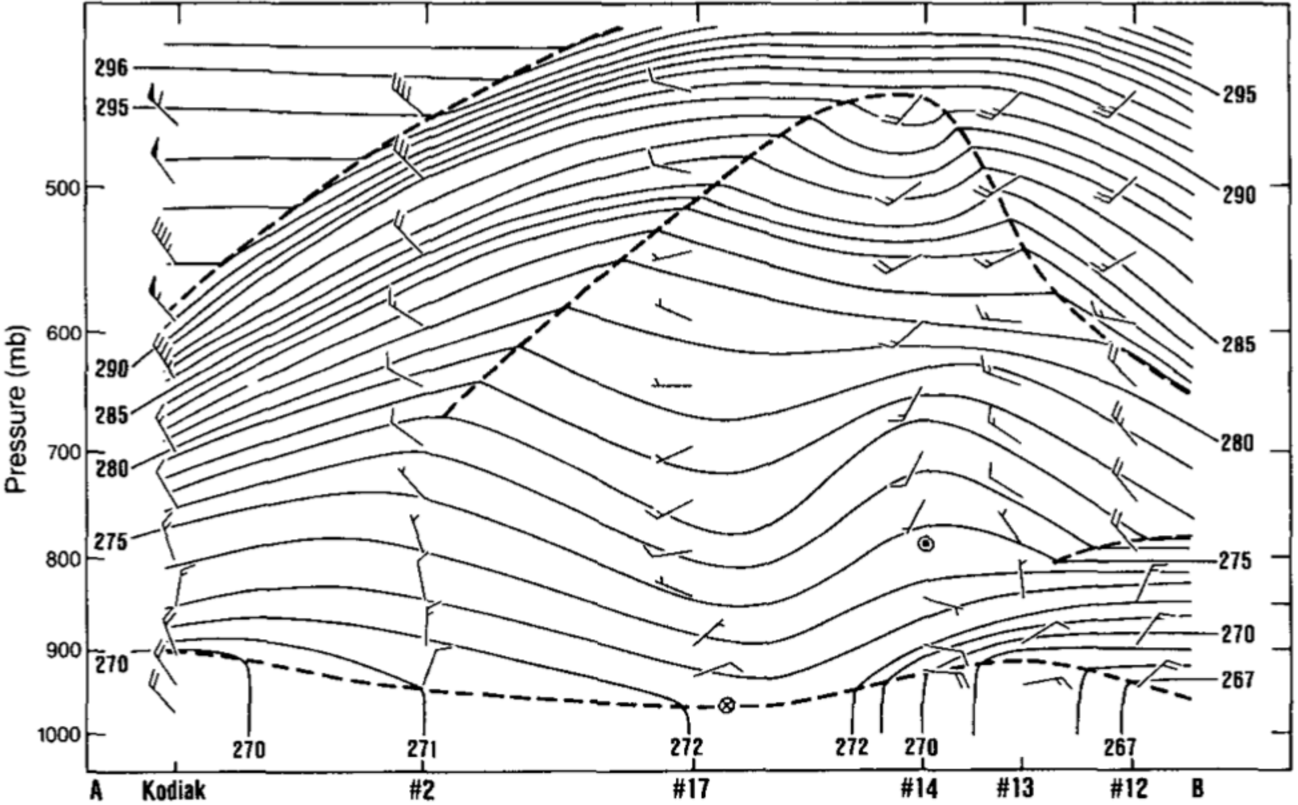


Adapted from Montgomery and Farrell (1992)

- Geostrophic wind vectors show that the circulation with PLs is:
  - Cyclonic
  - Confined to near the surface
- Circulation driven by upper level PV interaction and diabatic destabilization
  - As we will see later…
- Note:
  - Doubly periodic domain in their model!
  - Z = 0.5 is about mid-troposphere

Warm Core Nature

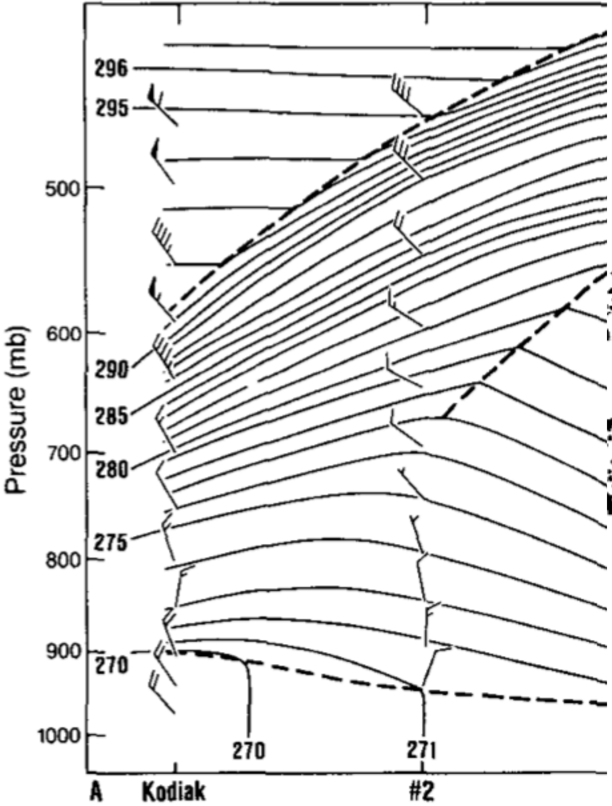
Potential Temperature

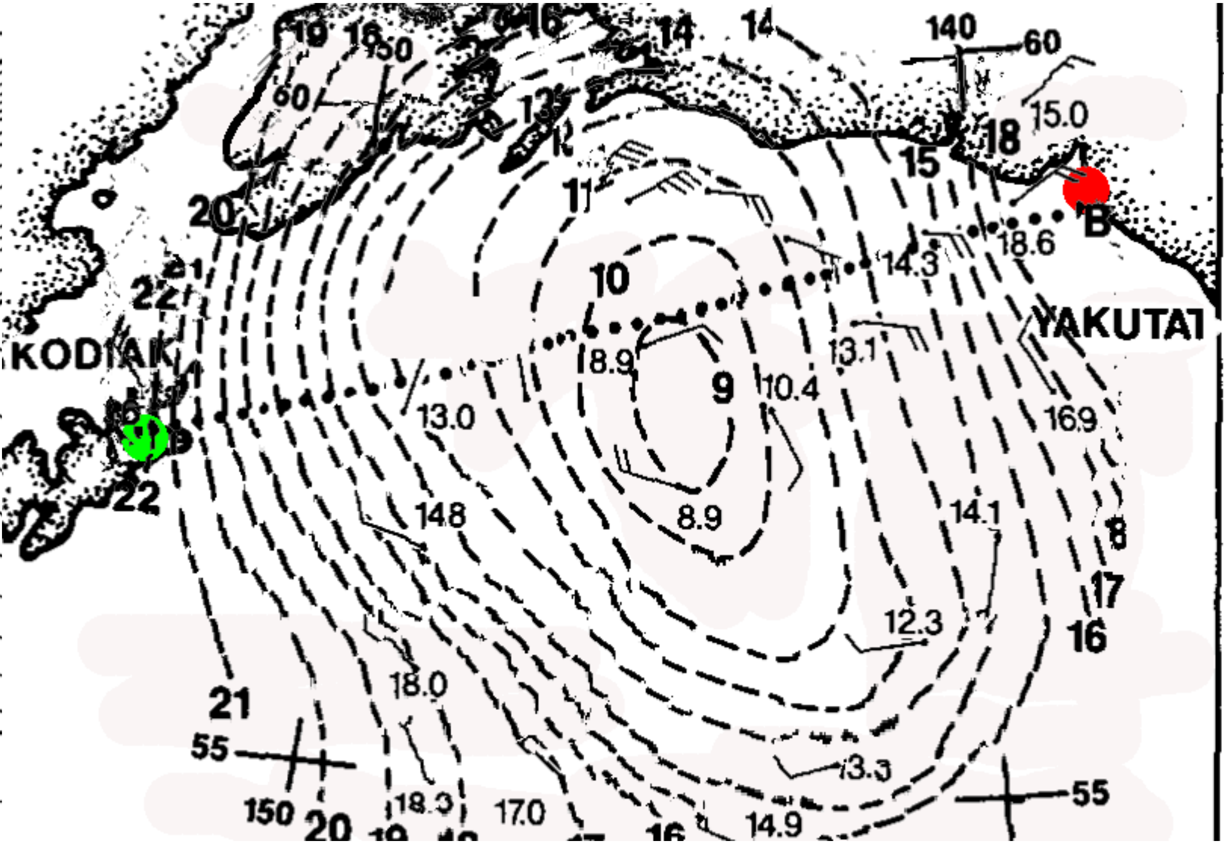


Adapted from Douglas et al. 1991

Warm Core Nature

Potential Temperature



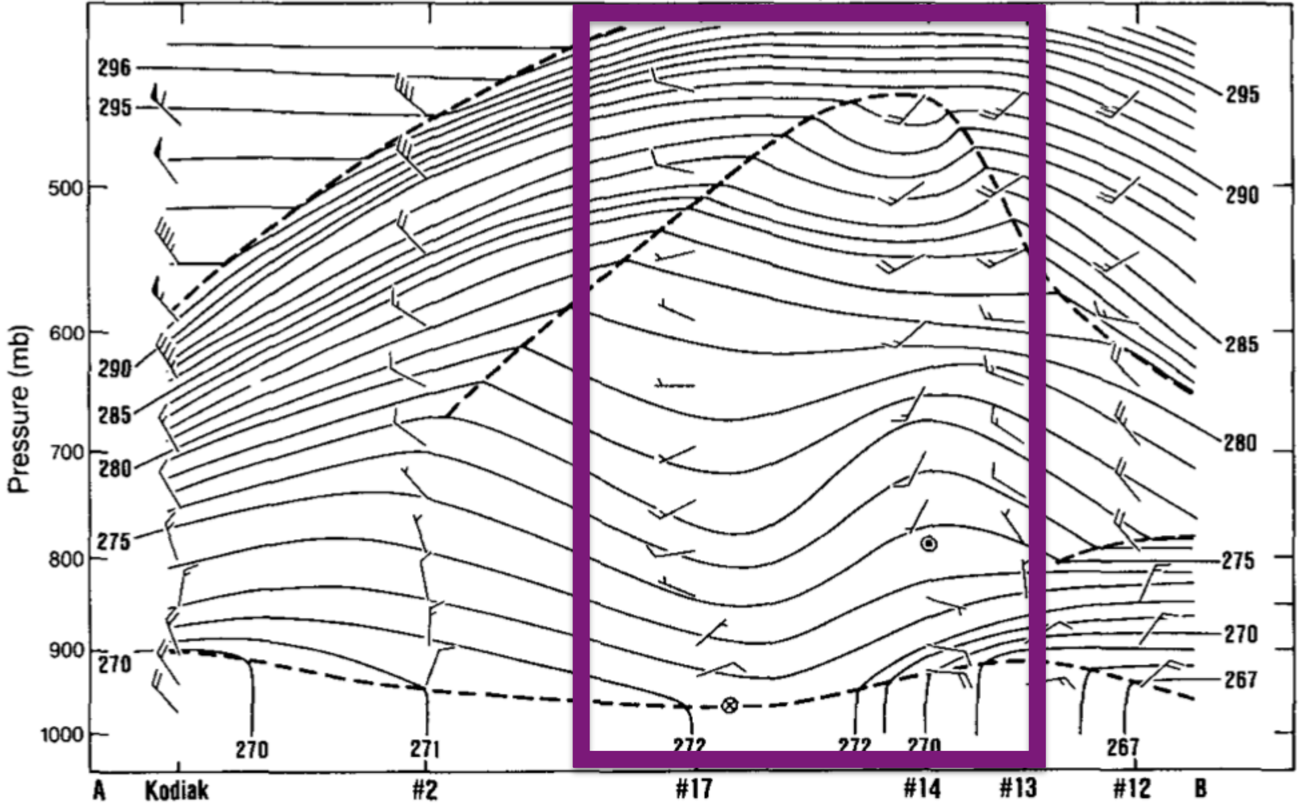


Adapted from Douglas et al. 1991

FIG. 12. Difference in potential temperature between 550 and 950 mb, 0000 UTC 5 March, with 925-mb winds from ODWs and aircraft soundings (no values) included to show polar low position. Contour interval is 1°C. The "A" and "B" are the ends of the cross section in Fig. 13.

Warm Core Nature

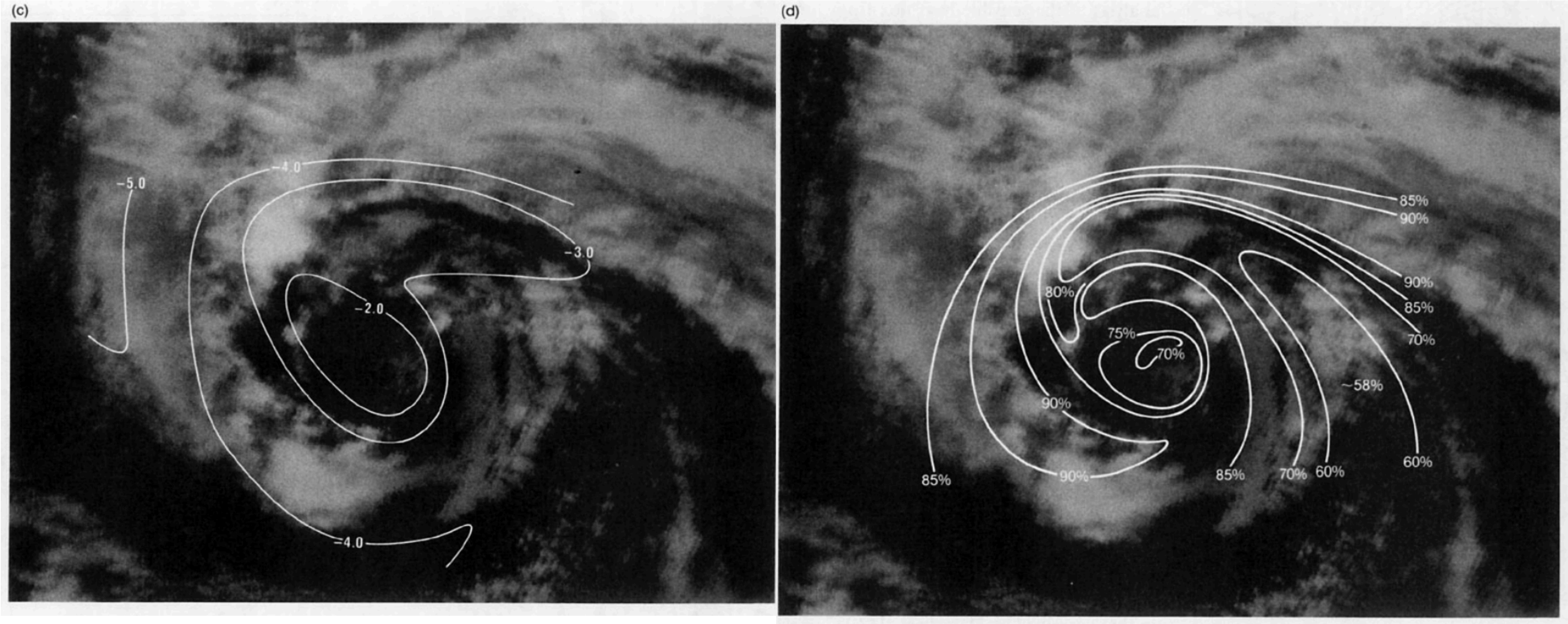
Potential Temperature



Adapted from Douglas et al. 1991

- Strong static stability aloft
- Tilted warm core
- Low-level cyclonic winds extend pretty far out
- More unidirectional aloft

Warm Core Nature

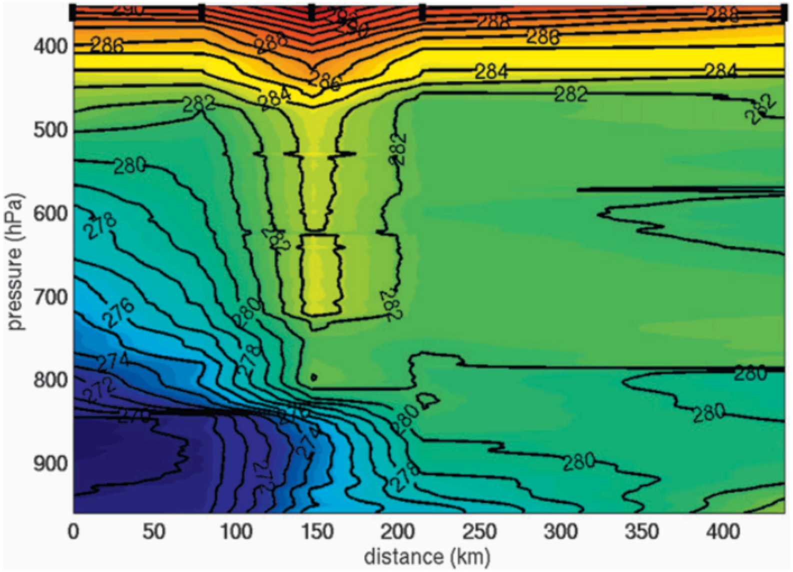


Isotherms (°C) 960 hPa

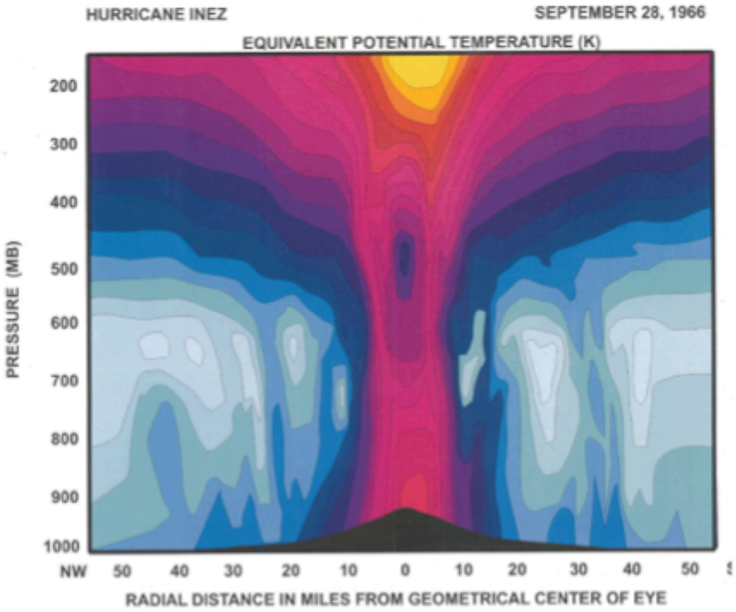
RH (%) 960 hPa

Adapted from Douglas et al. 1991

Observed "Theta-E Tubes"



Linders and Saetra
2010

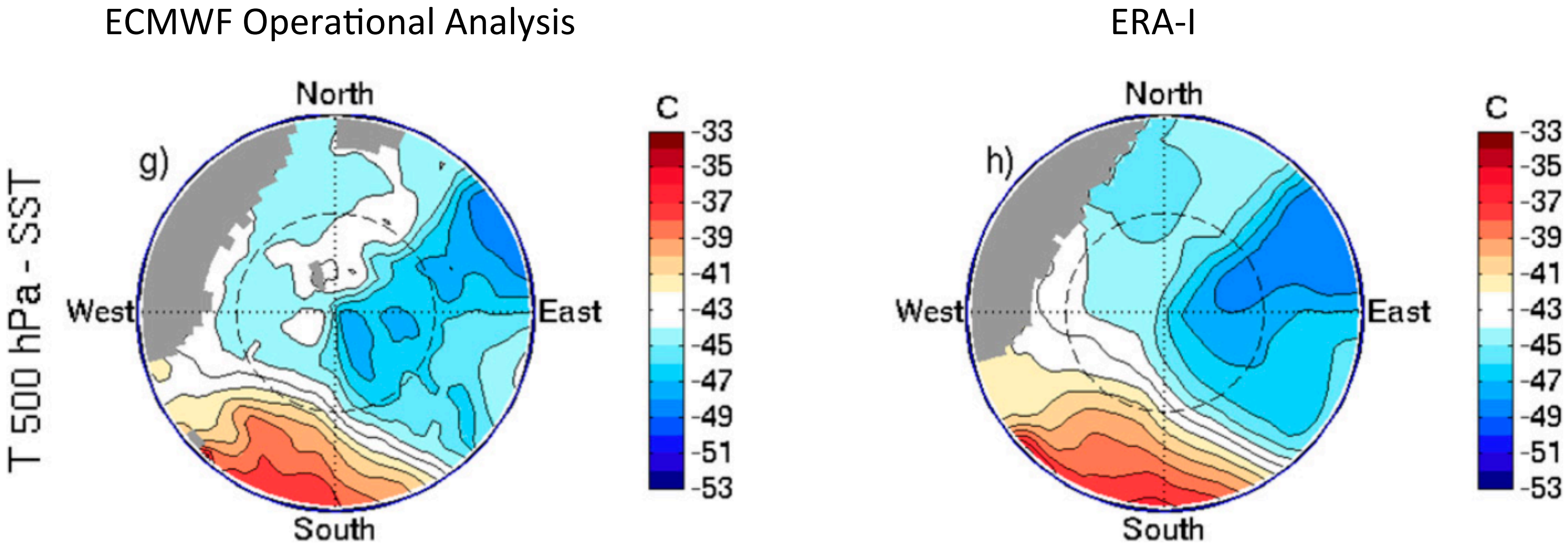


Radial-vertical cross-section of θ_e from Hawkins and Imbembo (1966) for Hurricane Inez. Highest values are warm colors, lower values cool colors. This figure was colorized by a student of Kerry Emanuel.

Obtained directly from Molinari
2015 "Tropical Cyclone
Observations" Lecture Notes

PL Low-level Atmospheric Stability

Zappa et al. (2014)

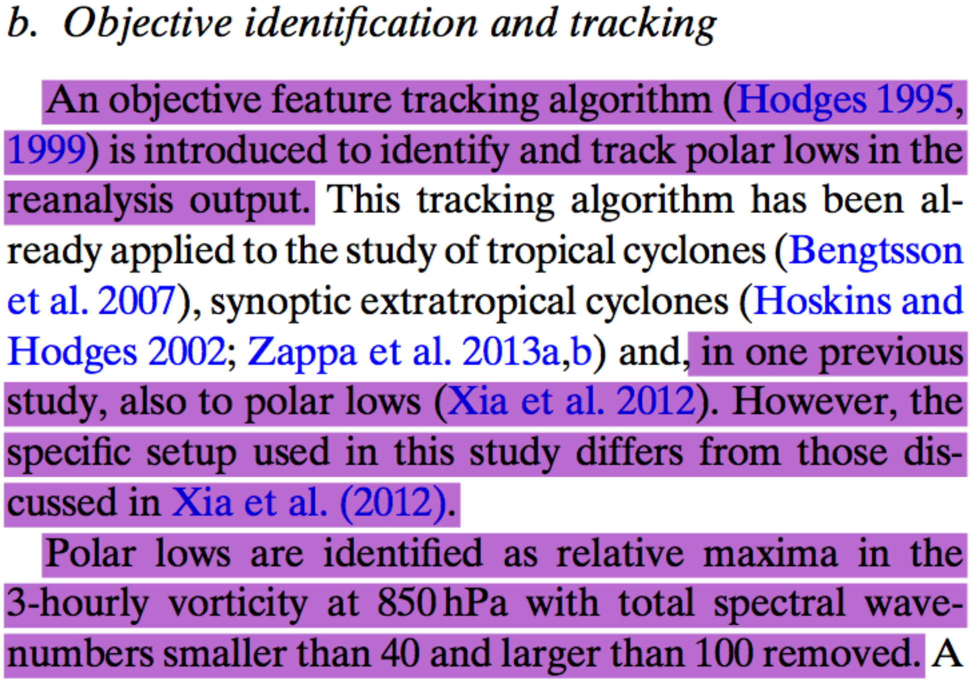


ECMWF Operational Analysis

ERA-I

- PLs tend to have appreciable low-level instability, which is represented above
- Tend to have a criterion of ≤ – 43° C

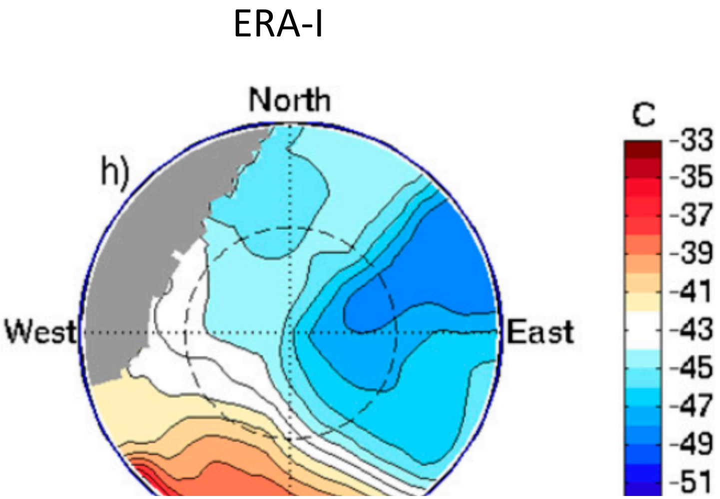
PL Low-level Atmospheric Stability



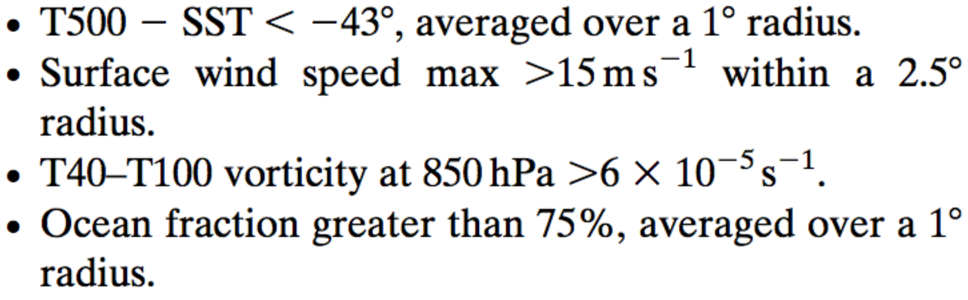
b. Objective identification and tracking

An objective feature tracking algorithm (Hodges 1995, 1999) is introduced to identify and track polar lows in the reanalysis output. This tracking algorithm has been already applied to the study of tropical cyclones (Bengtsson et al. 2007), synoptic extratropical cyclones (Hoskins and Hodges 2002; Zappa et al. 2013a,b) and, in one previous study, also to polar lows (Xia et al. 2012). However, the specific setup used in this study differs from those discussed in Xia et al. (2012).

Polar lows are identified as relative maxima in the 3-hourly vorticity at 850 hPa with total spectral wavenumbers smaller than 40 and larger than 100 removed. A

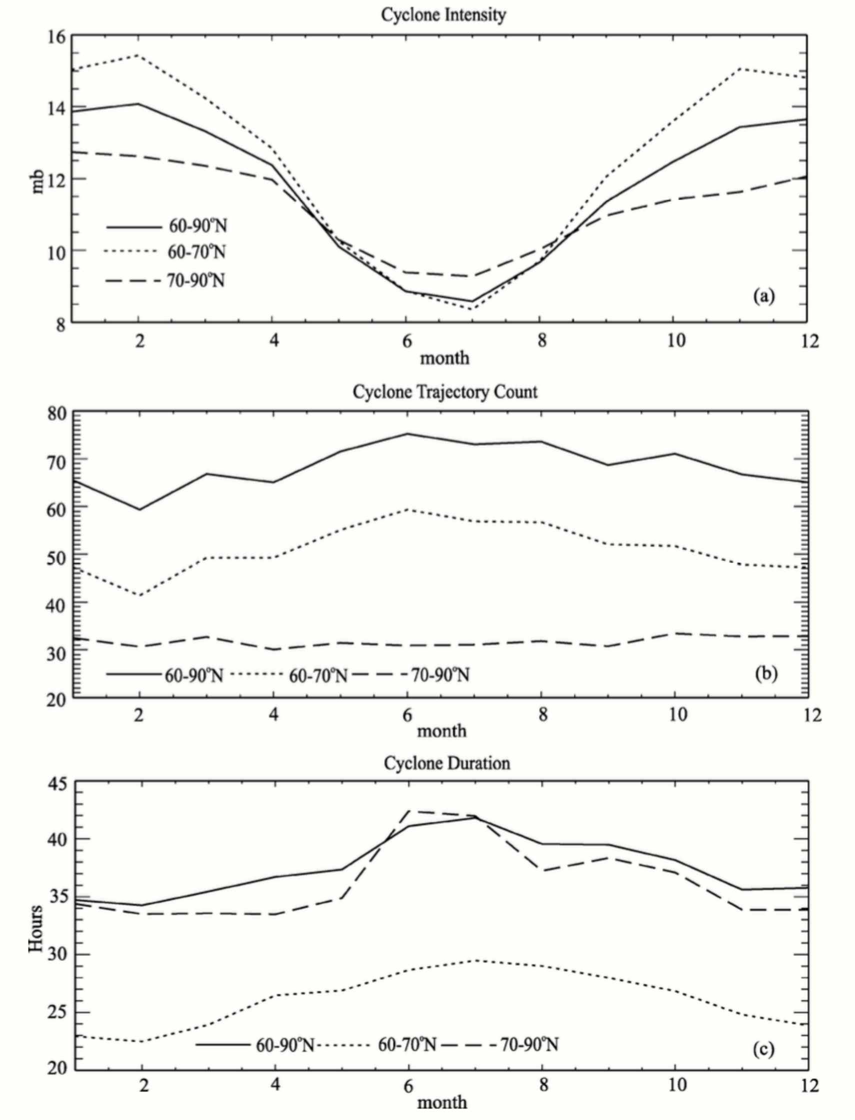


- PLs tend to have appreciable low-l
  above
- Tend to have a criterion of ≤ − 43°



- $T500 - SST < -43^\circ$, averaged over a 1° radius.
- Surface wind speed max $>15\,\mathrm{m\,s^{-1}}$ within a 2.5° radius.
- T40–T100 vorticity at 850 hPa $>6 \times 10^{-5}\,\mathrm{s^{-1}}$.
- Ocean fraction greater than 75%, averaged over a 1° radius.

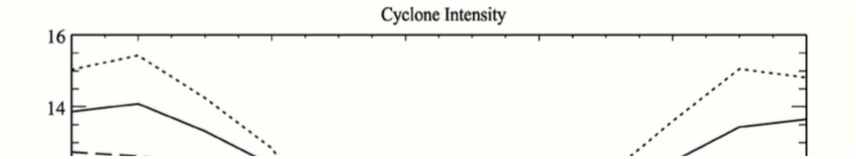
Where do PL's occur?



- Used 6-hourly SLP from the NCEP-NCAR reanalysis dataset poleward of 60 N
- Strength and Numbers tradeoff:
  - More in summer but weaker and longer lived
  - Less in winter but stronger and shorter lived
- Transition from –AO to +AO shows increase of cyclone count in the arctic

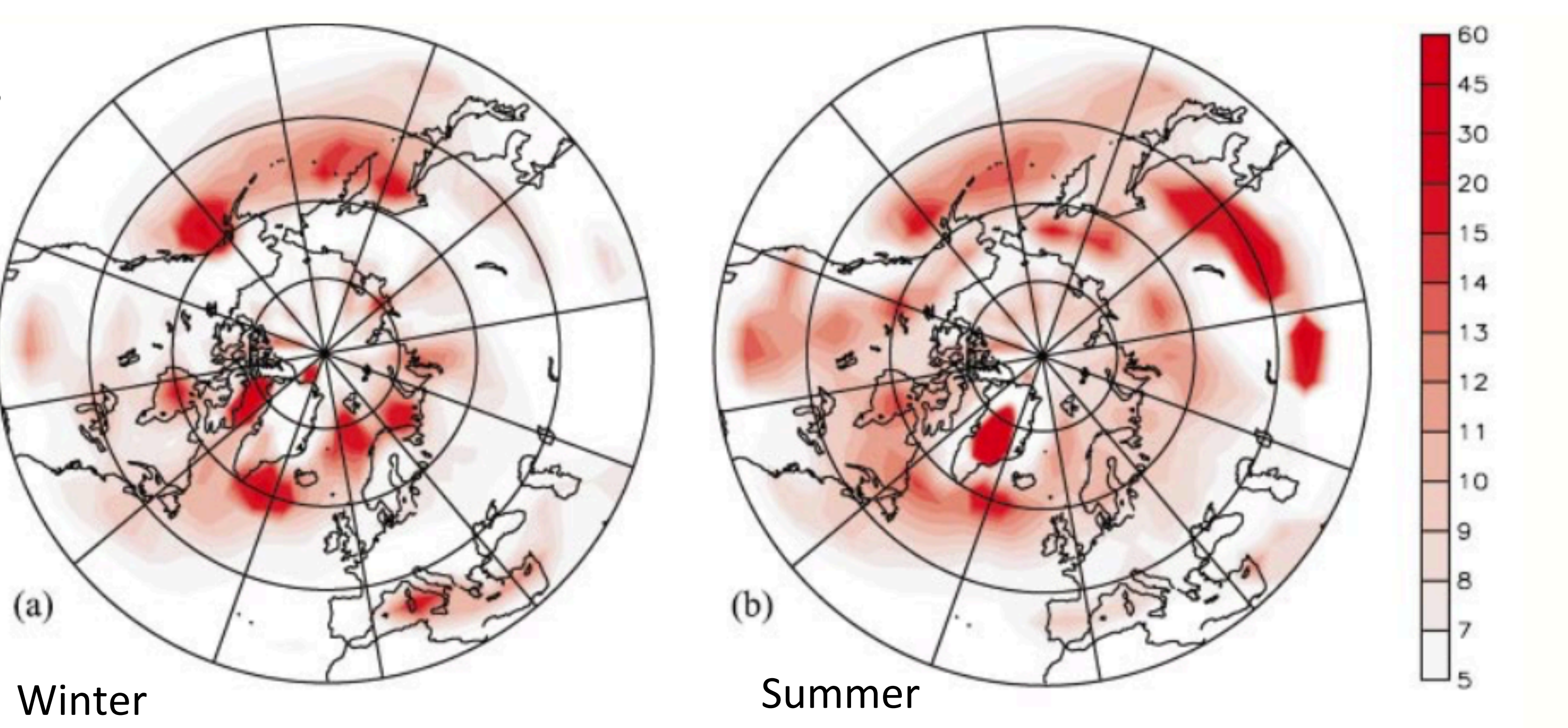
Adapted from Zhang et al. (2004)

Where do PL’s occur?



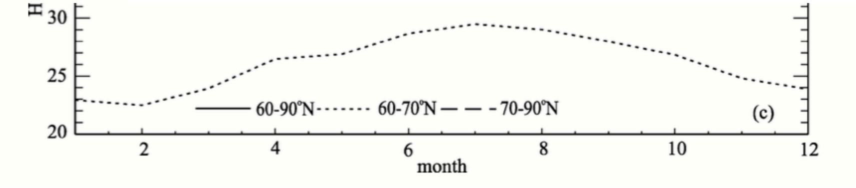
- Used 6-hourly SLP from the NCEP-NCAR reanalysis

Counts per 10^5 km^2



Winter

Summer



Adapted from Zhang et al. (2004)

Can I choose a flavor?

- Balance between:
  - Presence of upper level cold trough/PV anomaly
  - Strength of baroclinicity
  - Strength and direction of shear
  - Size of initial disturbance and radius of maximum horizontal wind (RWM)
  - PBL moisture
  - Presence of CISK

Can I choose a flavor?

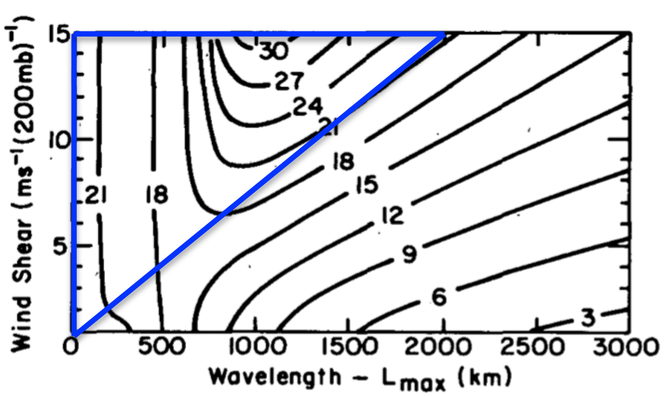


FIG. 7. Maximum growth rate $(10^{-6}\ s^{-1})$ plotted as a function of wind shear in the 700–900 mb layer and wavelength for the BCD/CISK mode with $\hat{r}_8 = 0.7$.

Adapted from Sardie and Warner (1983)

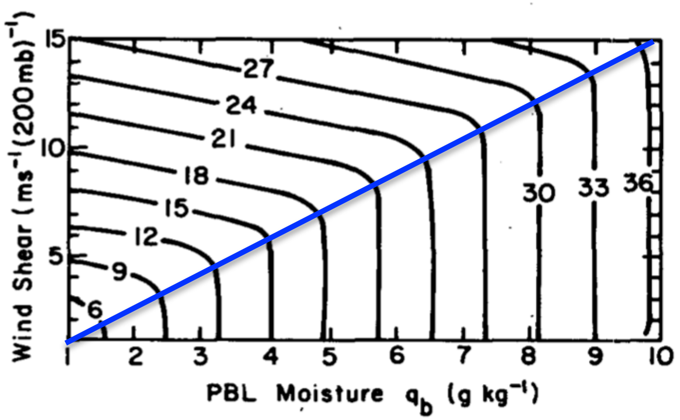


FIG. 9. Maximum growth rate $(10^{-6}\ s^{-1})$ plotted as a function of wind shear in the 700–900 mb layer and PBL moisture for the BCD/CISK mode.

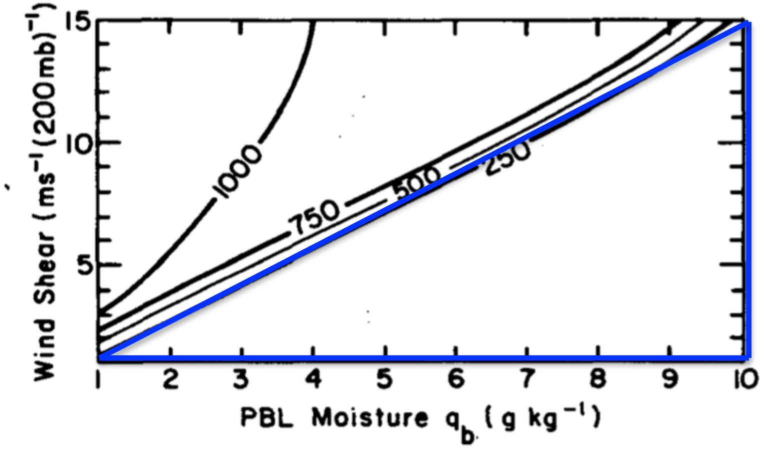
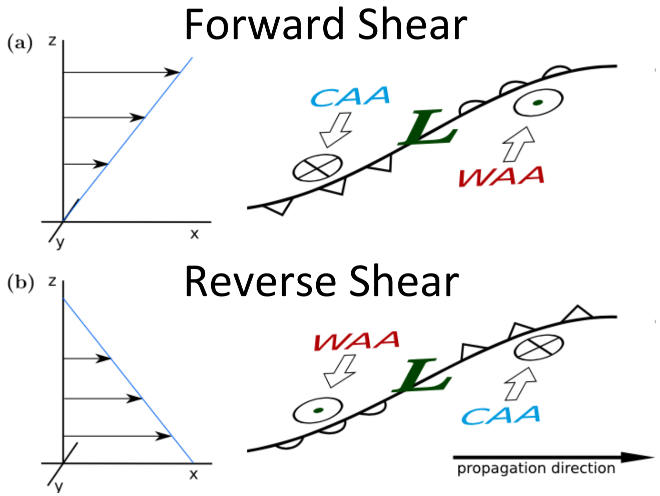


FIG. 8. Wavelength of maximum growth rate (km) plotted as a function of wind shear in the 700–900 mb layer and PBL moisture for the BCD/CISK mode.

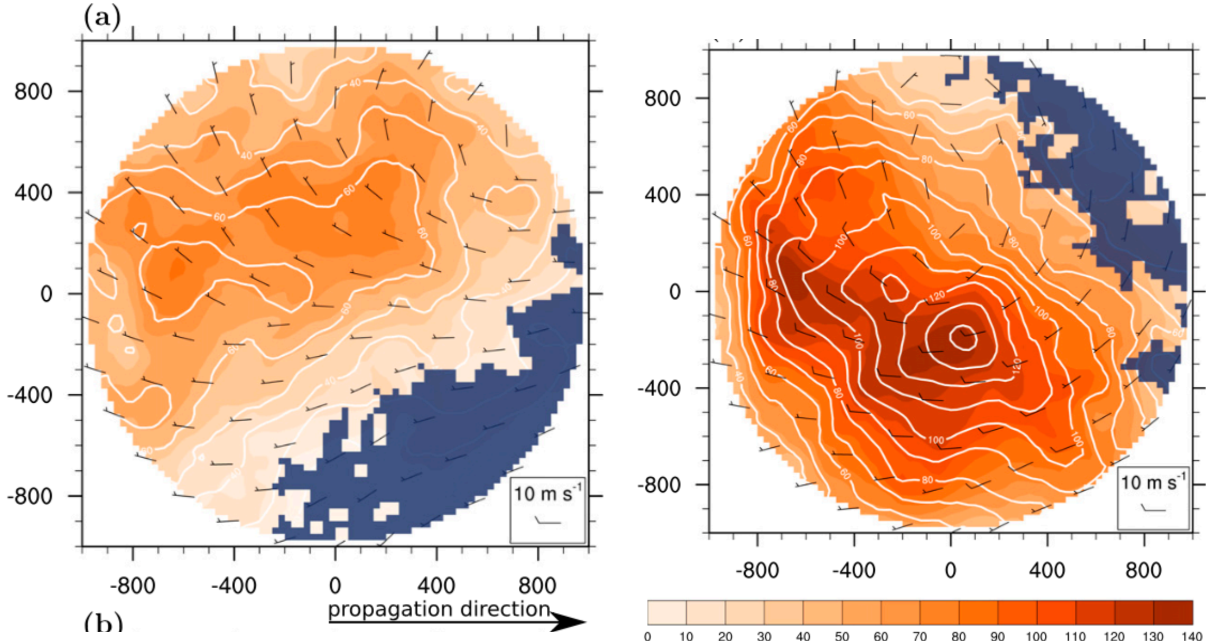
Can I choose a flavor?



Forward Shear

Reverse Shear

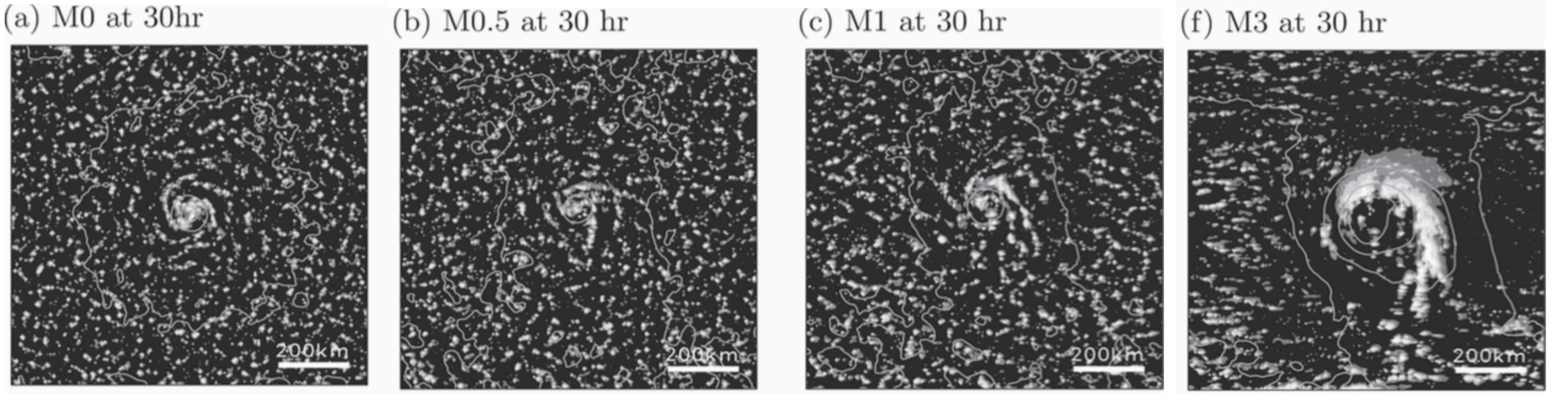
- Because of their warm core nature, PLs will generally be reverse shear
- Reverse shear environments will have enhanced surface heat flux
  - Better for convection!!!!!!



Adapted from Terpstra et al. (2016)

FIG. 10. Composites in the rotated frame of the surface sensible heat flux (W m^{-2}; shading), latent heat flux (W m^{-2}; solid lines), and wind at 10 m (wind barbs) for (a) forward and (b) reverse shear conditions. Areas with less than 75% of ocean are masked. Values on the axes indicate the distance (km) from the genesis location.

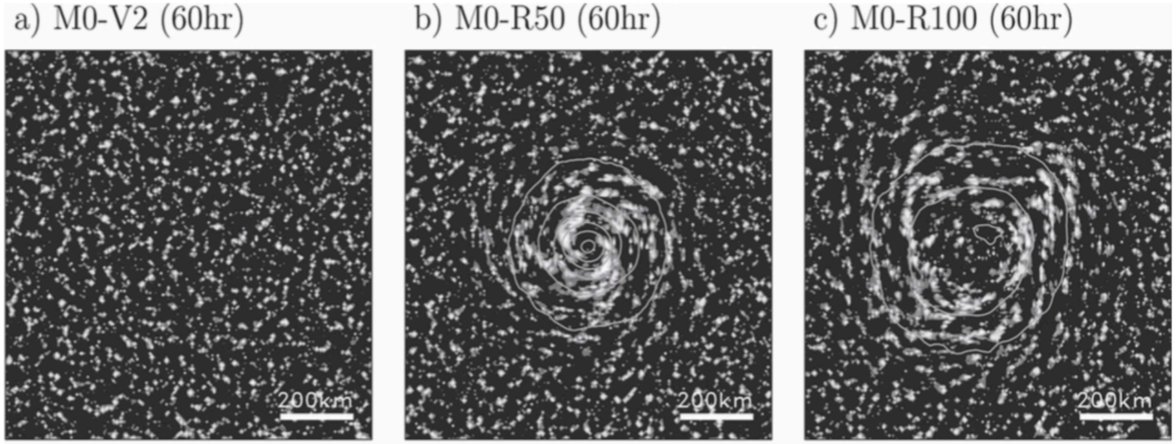
Can I choose a flavor?



Baroclinicity (Shear) →

R_o=20km

V_o=7 m s^{-1}

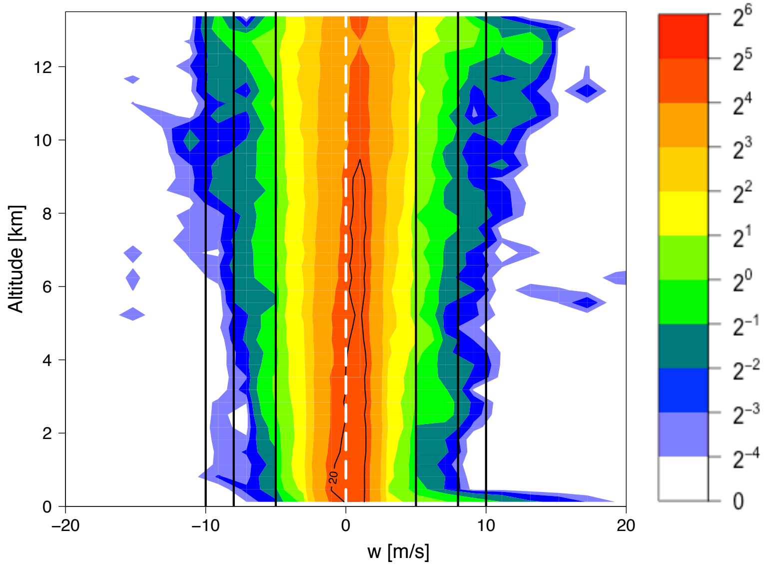


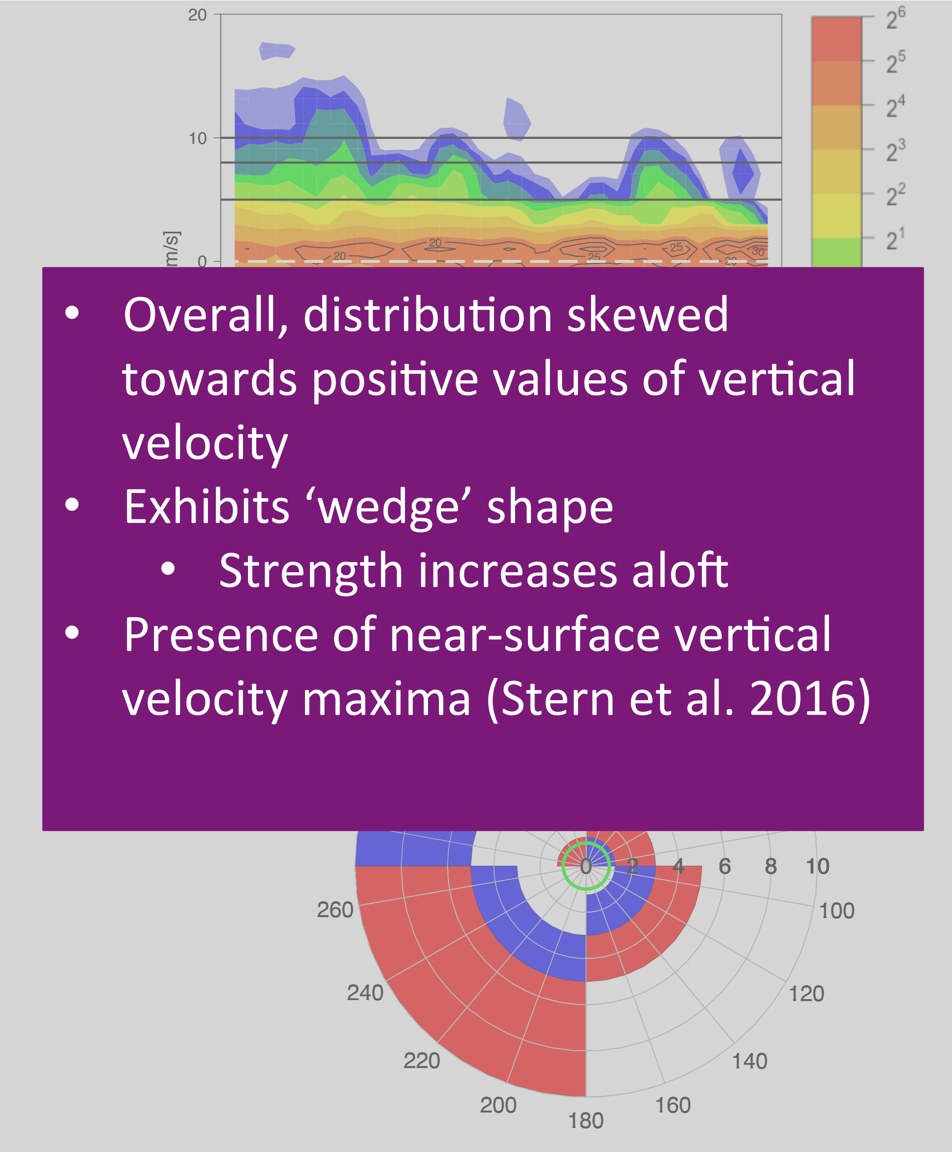
Vertically integrated total condensed water (g kg^{-1}) and SLP (~3 hPa)

RMW →

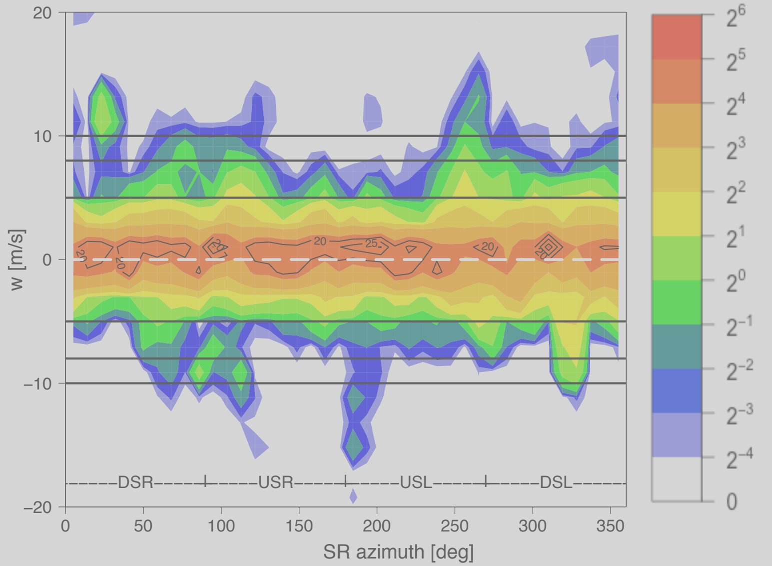
Adapted from Yanase and Niino 2007

What does TC Convection Look Like?

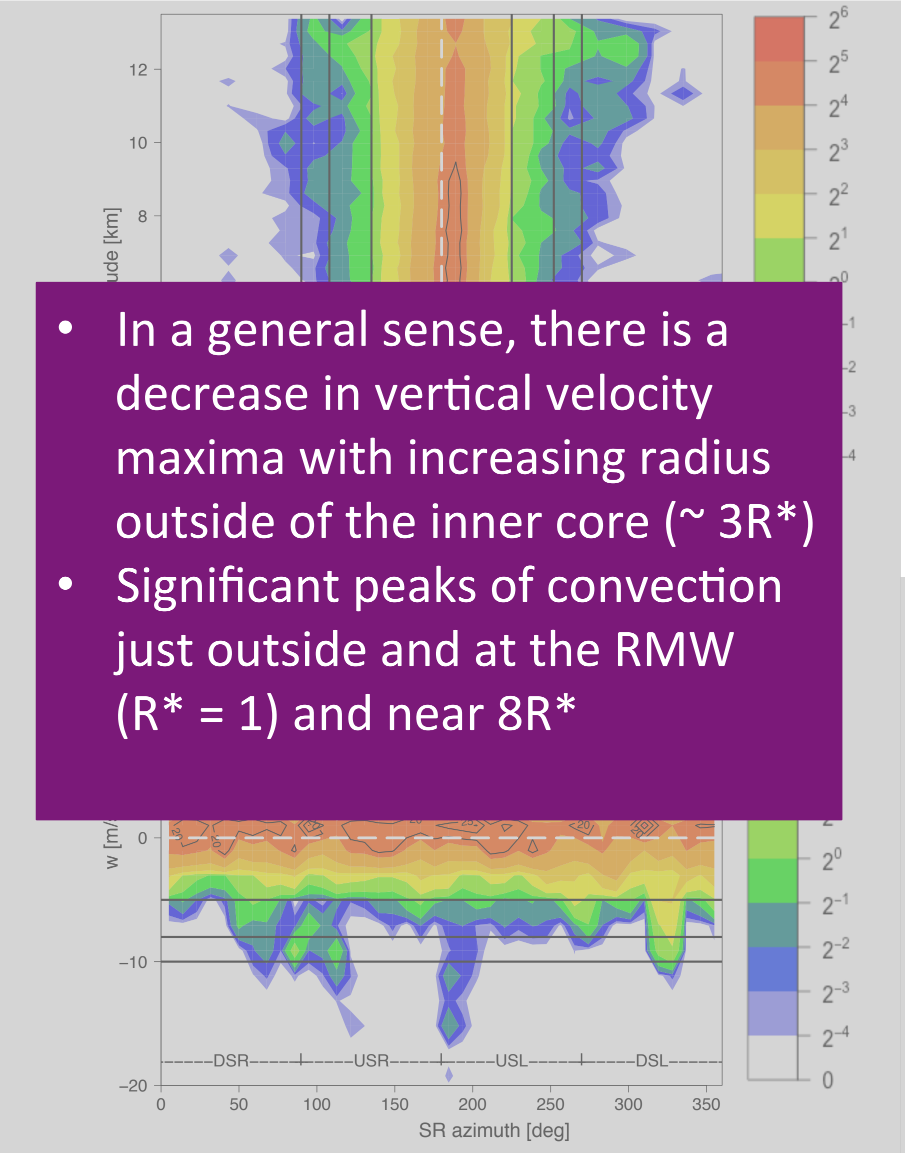




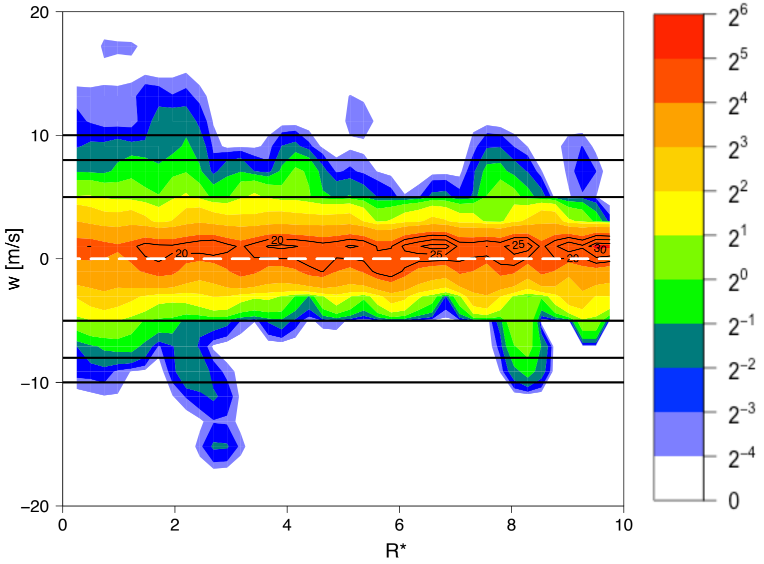
- Overall, distribution skewed towards positive values of vertical velocity
- Exhibits ‘wedge’ shape
  - Strength increases aloft
- Presence of near-surface vertical velocity maxima (Stern et al. 2016)

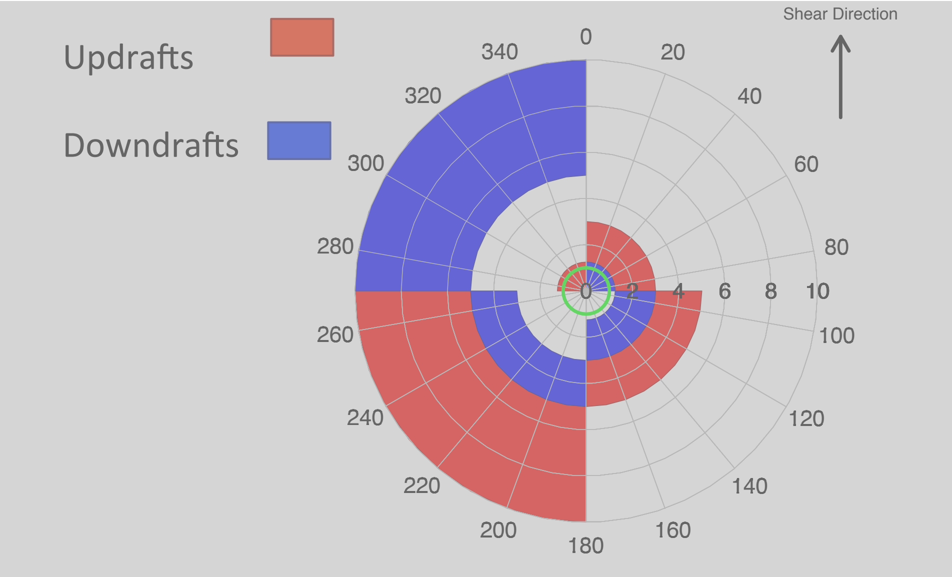


What does TC Convection Look Like?

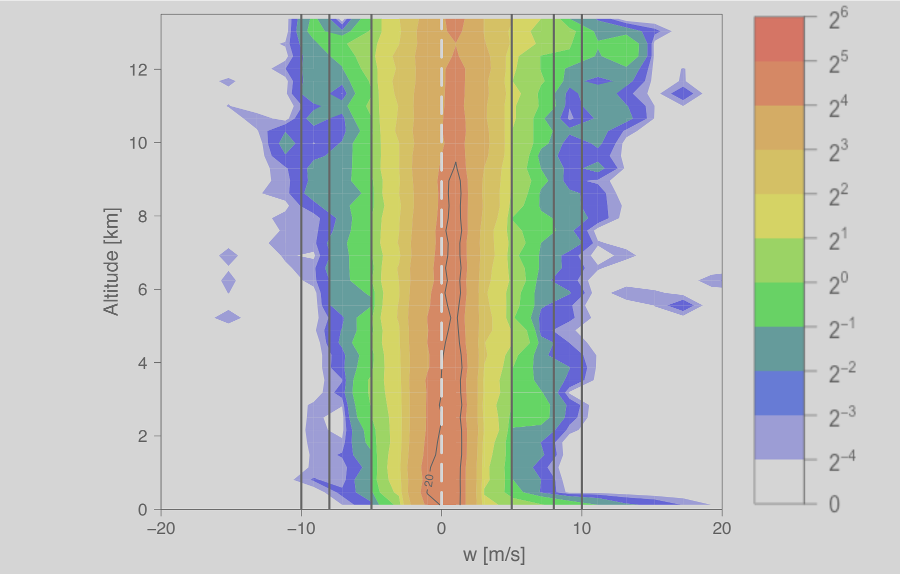


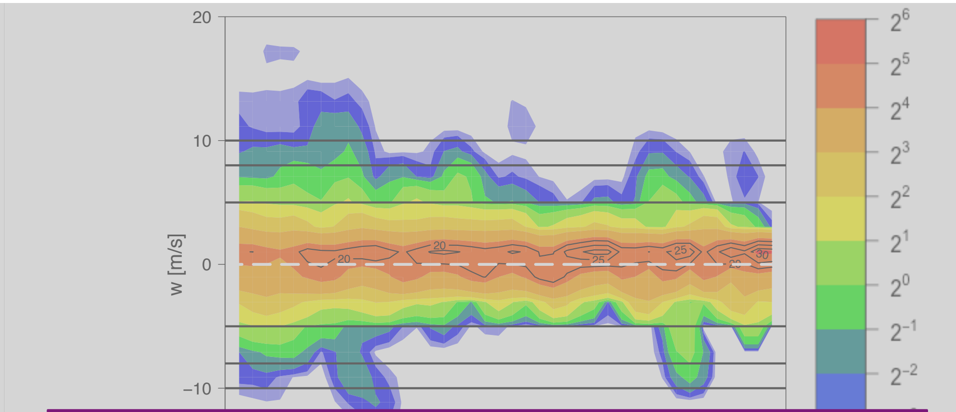
- In a general sense, there is a decrease in vertical velocity maxima with increasing radius outside of the inner core (~ 3R*)
- Significant peaks of convection just outside and at the RMW (R* = 1) and near 8R*



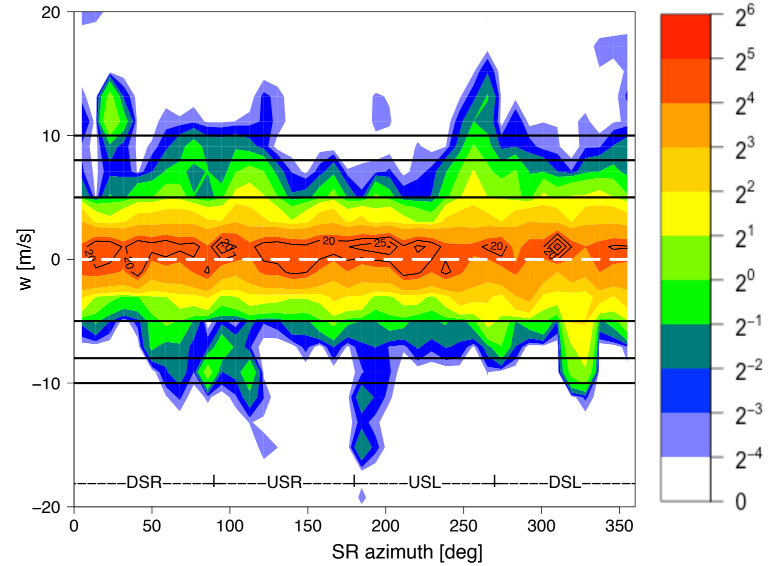


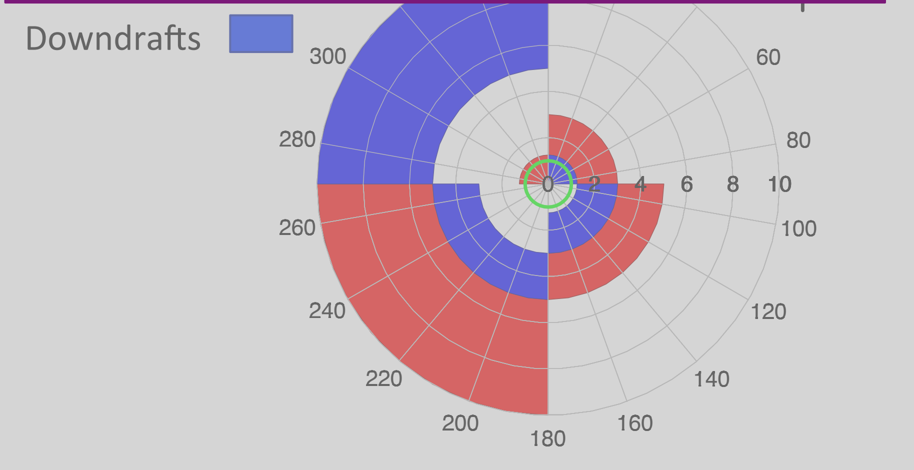
What does TC Convection Look Like?



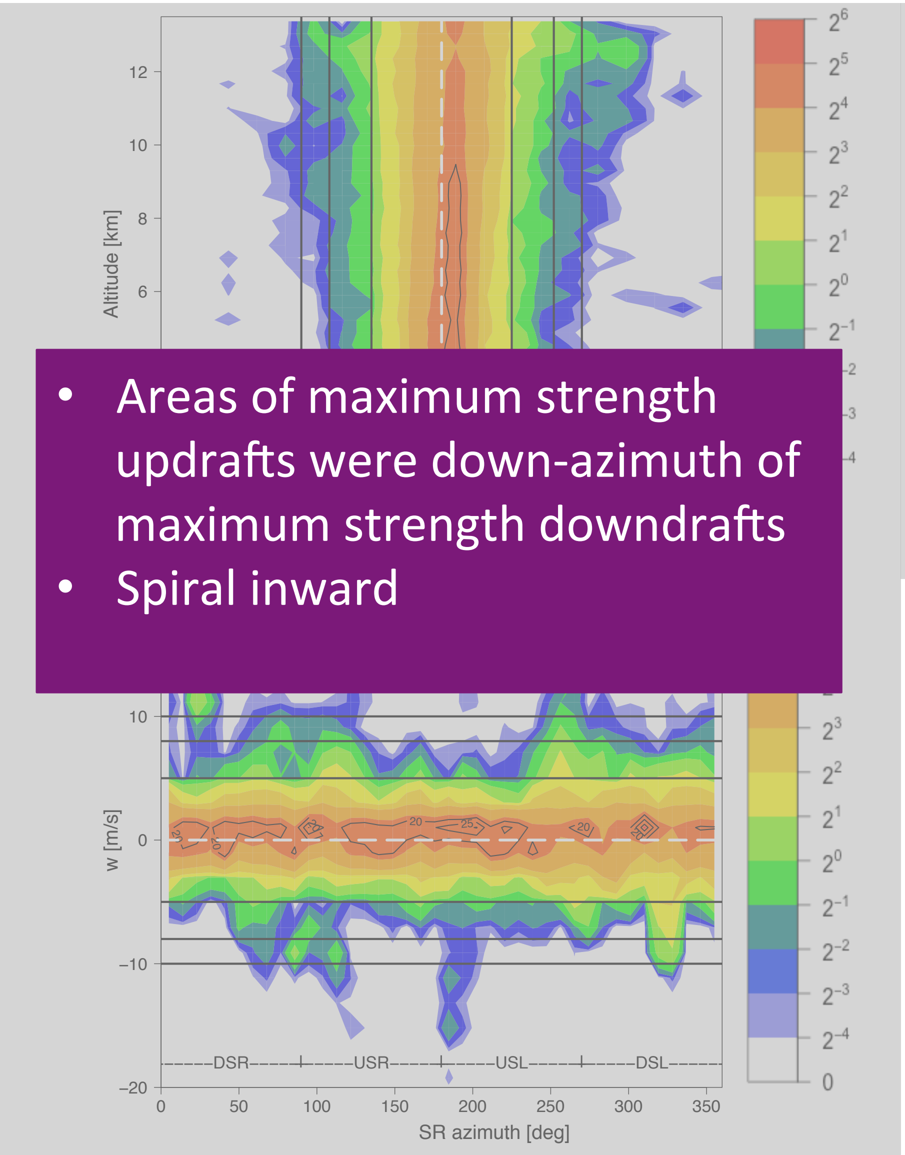


- Episodic peaks across all azimuth
- Highest percentages are above 30% with updrafts in the downshear-left quadrant





What does TC Convection Look Like?



- Areas of maximum strength updrafts were down-azimuth of maximum strength downdrafts
- Spiral inward