

**Vortex Rossby waves and secondary eyewall formation in a high-resolution simulation of Hurricane Katrina (2005)**

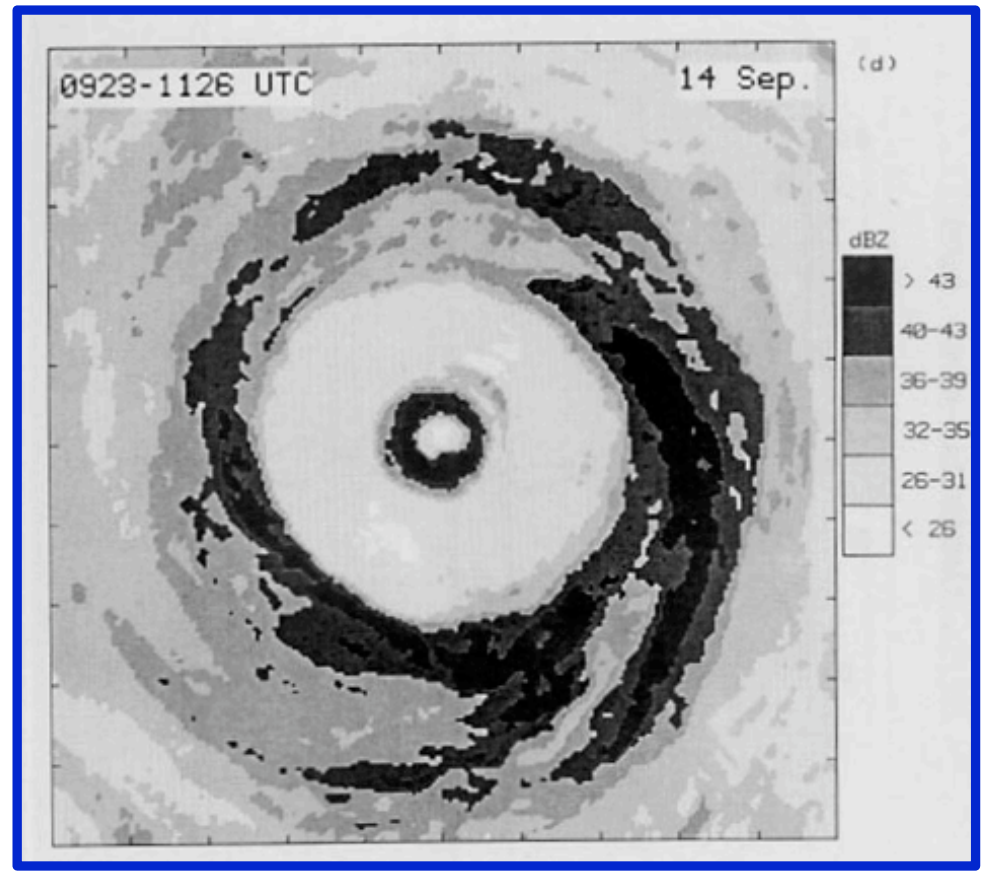
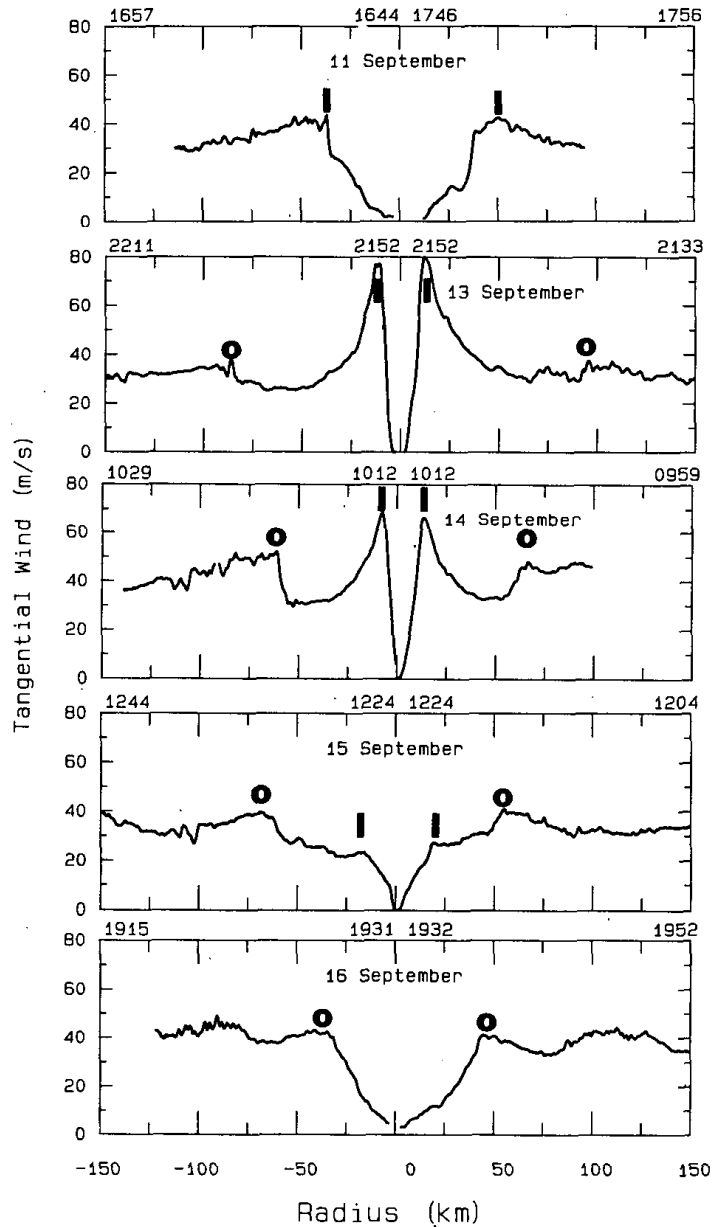


**Kristen L. Corbosiero**

**University at Albany, State University of New York**

**Sergio F. Abarca and Michael T. Montgomery**  
**Naval Postgraduate School**

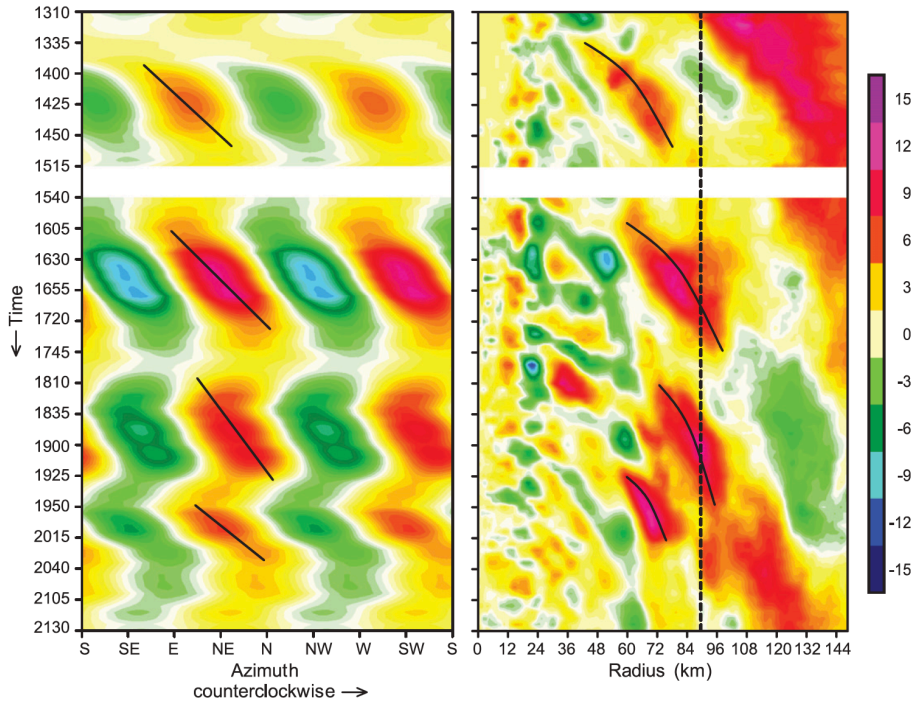
# Gilbert (1988)



The formation of a secondary eyewall is followed by an understood series of structural and intensity changes called an eyewall replacement cycle.

# Secondary eyewall formation hypotheses: Internal dynamics

## Vortex Rossby waves (VRWs)

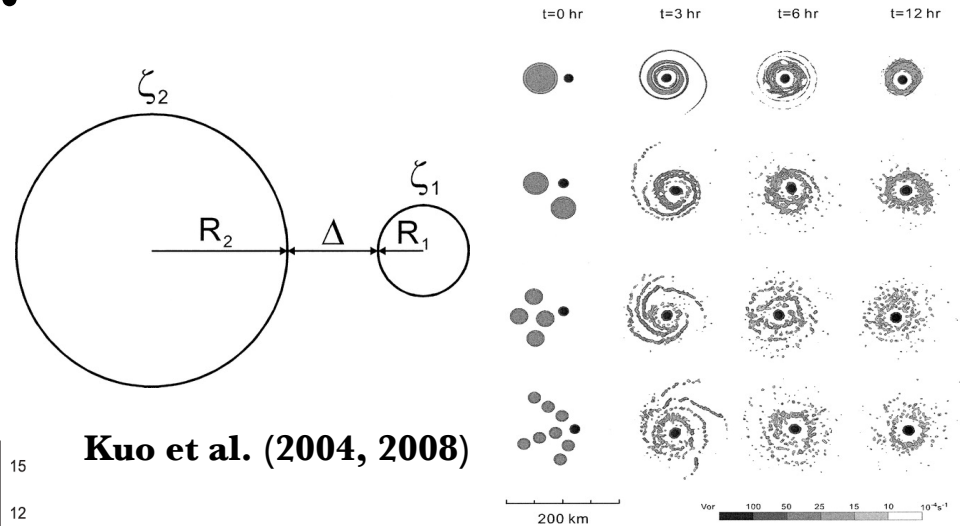


Montgomery and Kallenbach (1997)

Camp and Montgomery (2001)

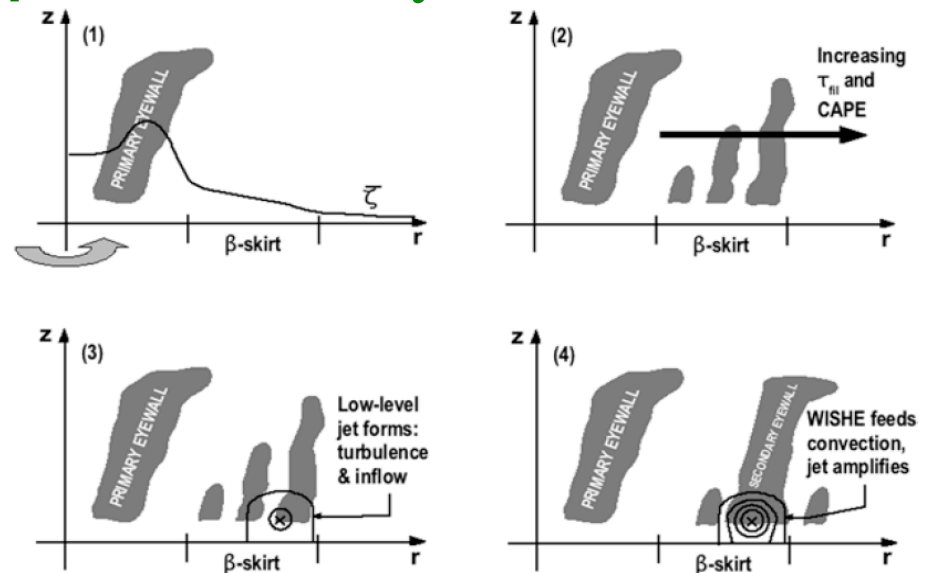
Corbosiero et al. (2005)

# Barotropic vortex interactions



Kuo et al. (2004, 2008)

## $\beta$ -Skirt axisymmetrization

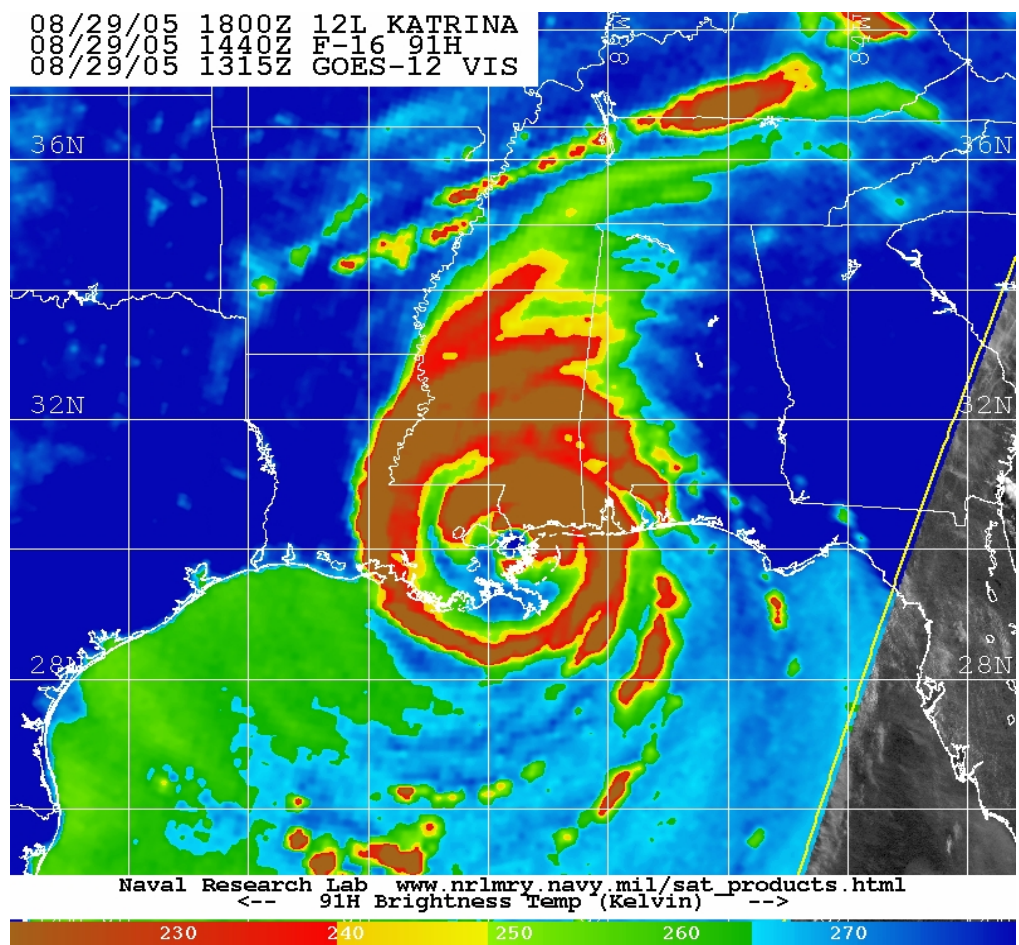
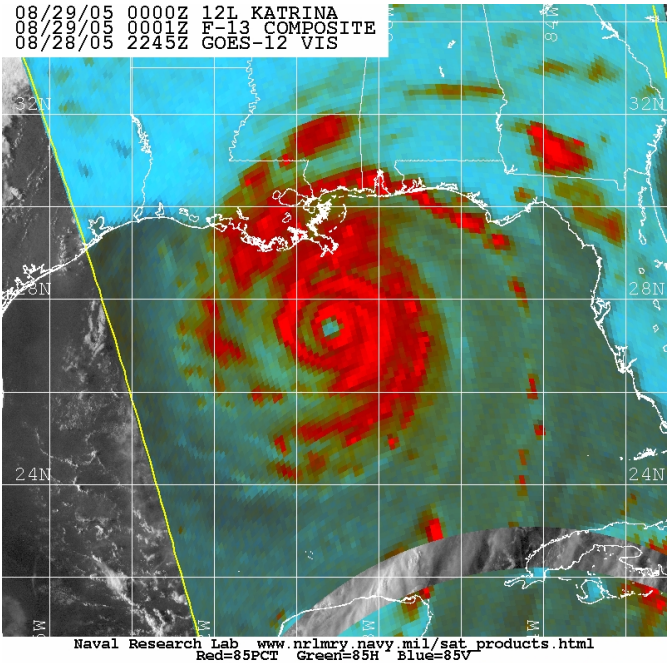
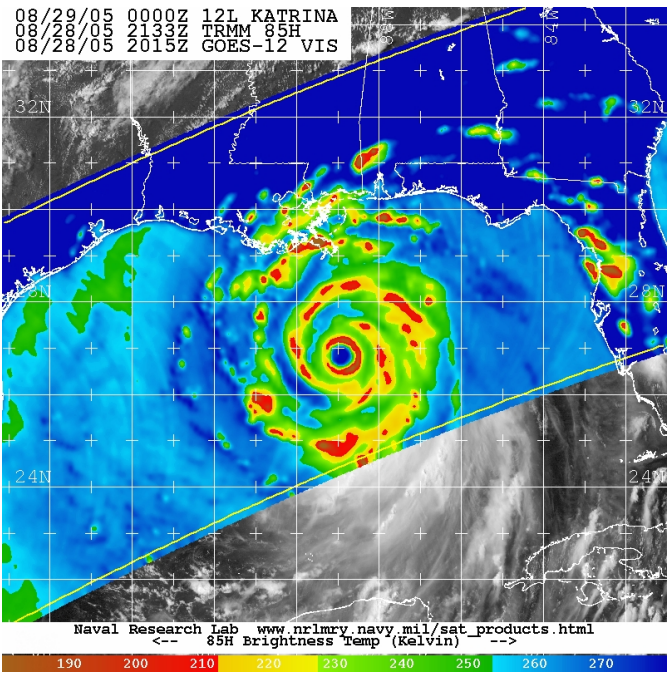


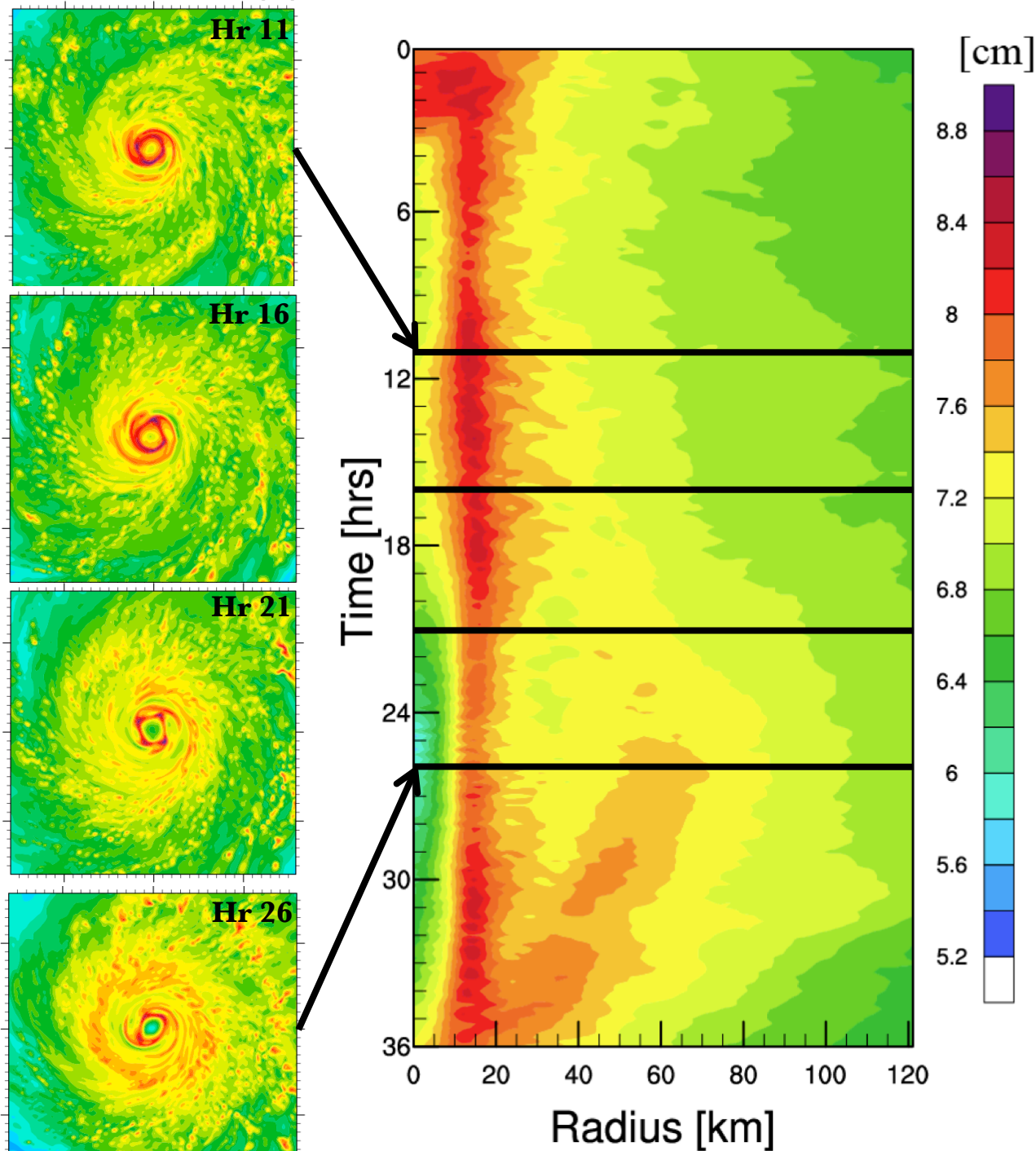
Tervey and Montgomery (2008)

# The Advanced Hurricane WRF (AHW)

- **Run in real-time at NCAR since 2004 and available at [http://www.wrf-model.org/plots/realtime\\_main.php](http://www.wrf-model.org/plots/realtime_main.php)**
- **Three domains (12, 4, 1.33 km) with two-way moveable nests that follow the hurricane center**
- **WRF version 2.1.2 with Kain-Fritsch cumulus parametrization (12 km only), WSM3 microphysics, YSU PBL scheme, drag (Donelan) and surface enthalpy coefficients (Carlson-Boland) for TCs {see *Davis et al.* (2008)}**
- **Initialized from the GFDL model at 0000 UTC 27 August 2005**

# Hurricane Katrina (2005): No in situ observations of a secondary eyewall, but convincing satellite evidence



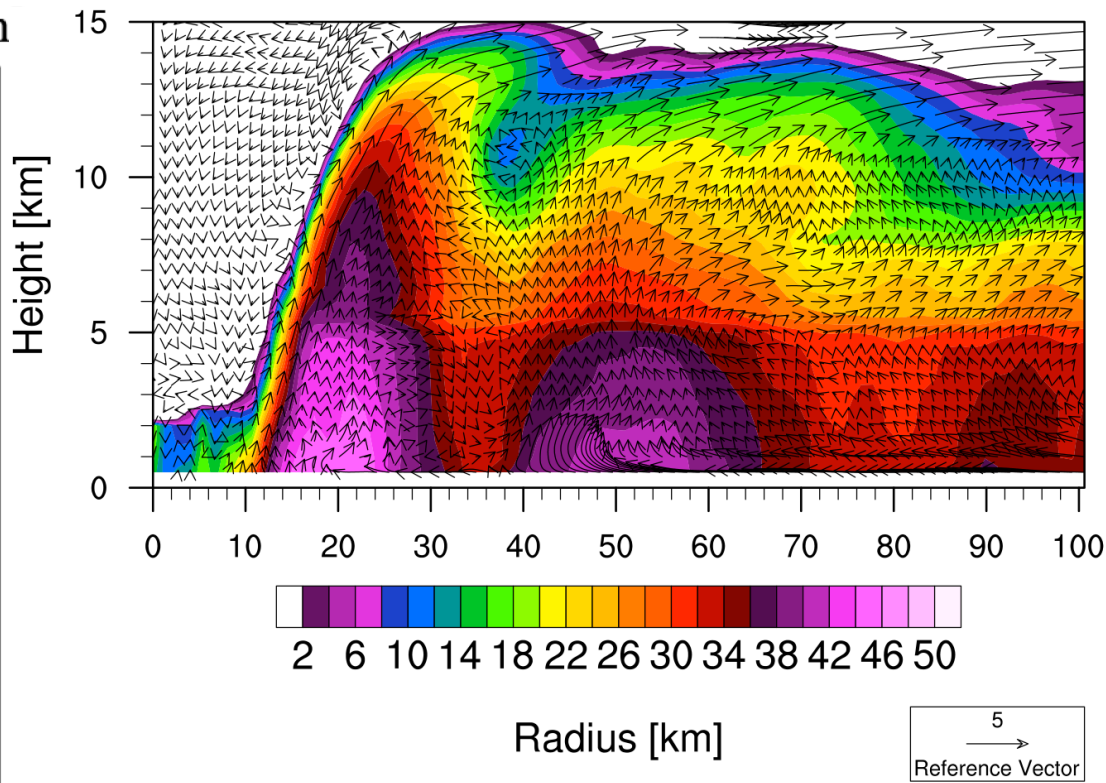
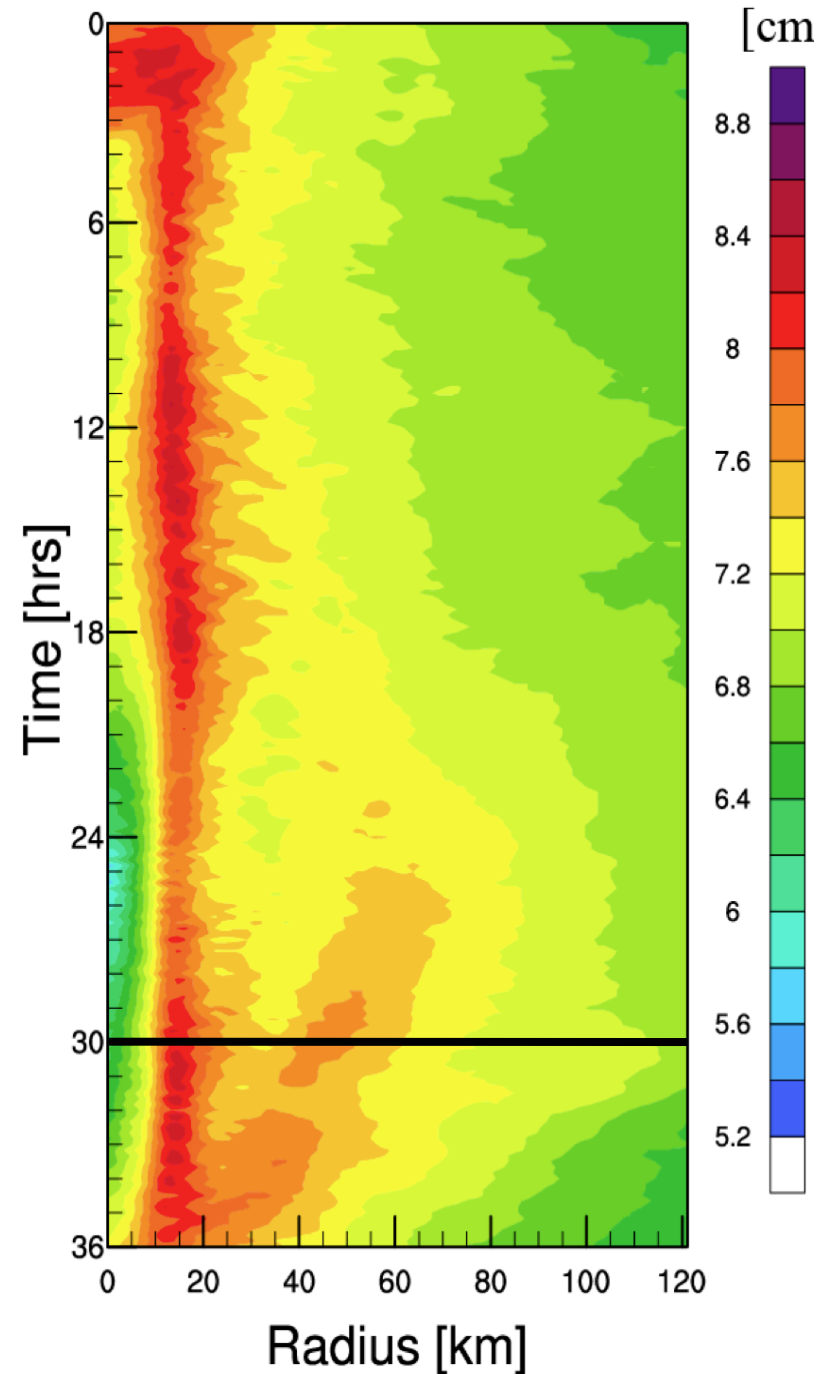


**Katrina (2005)**

**10 min time  
resolution  
from 00 UTC  
28 August (0 h)**

**Precipitable  
Water**

**Secondary  
eyewall first  
distinguishable  
at hour 25**

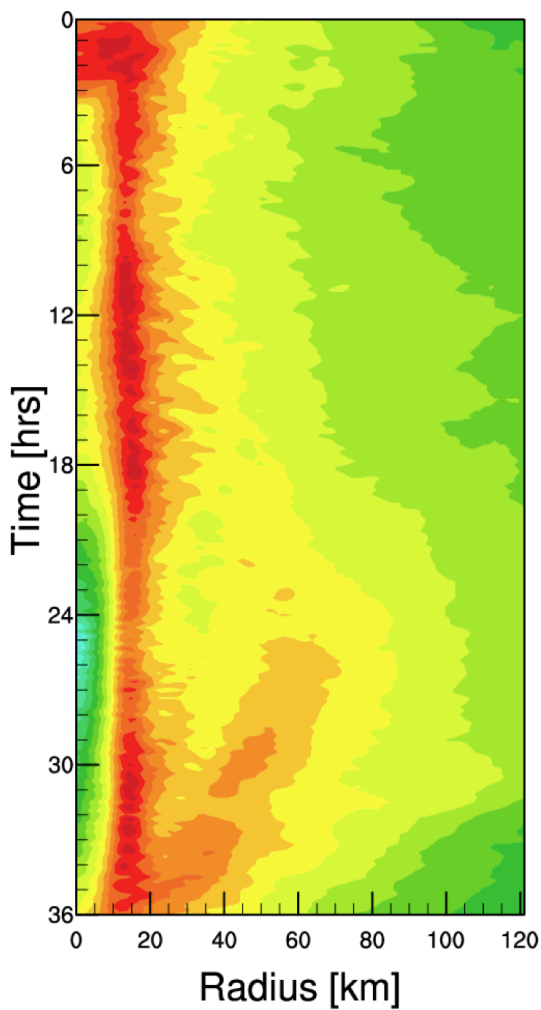


**Radius-height cross section**  
**Radar reflectivity at hour 30**

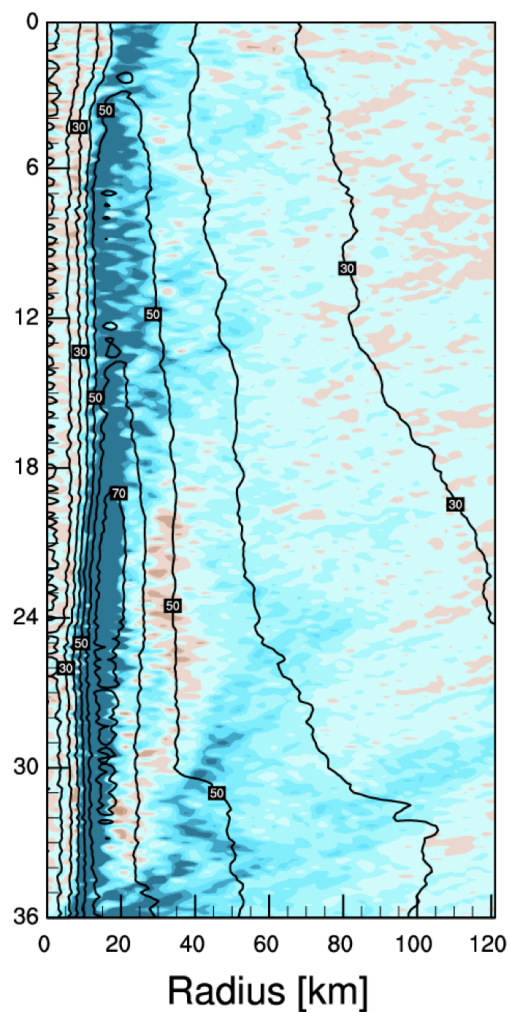
**Evidence of three eyewalls:**  
**Dying primary, growing secondary, developing tertiary**

# Katrina (2005)

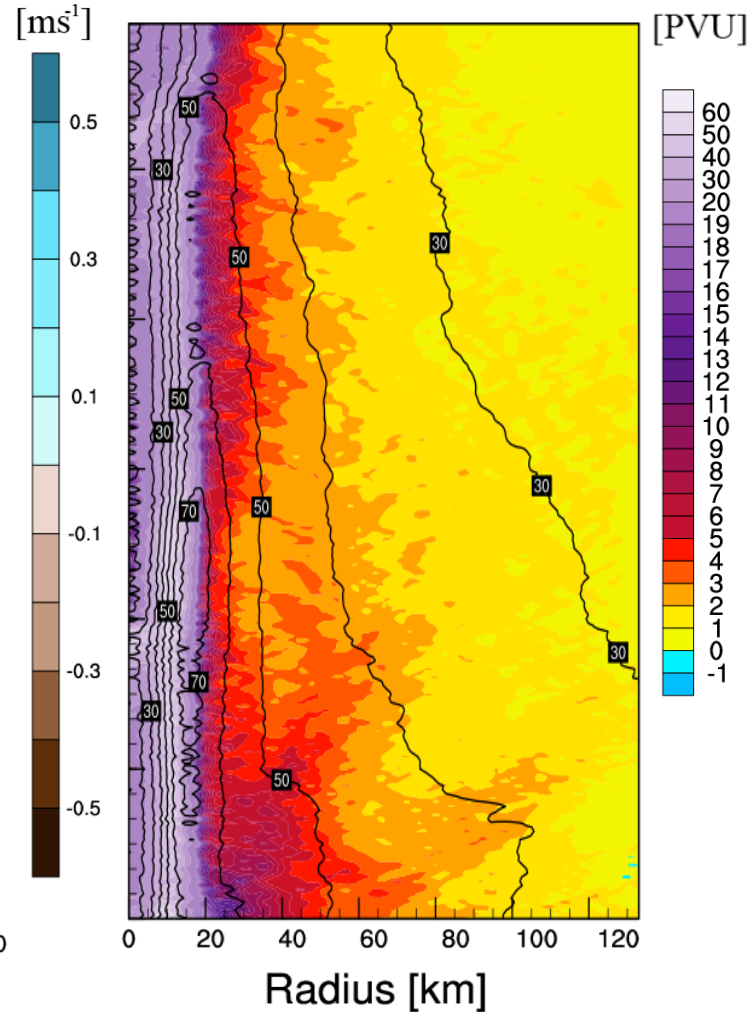
## Azimuthally averaged radius-time Hovmöllers



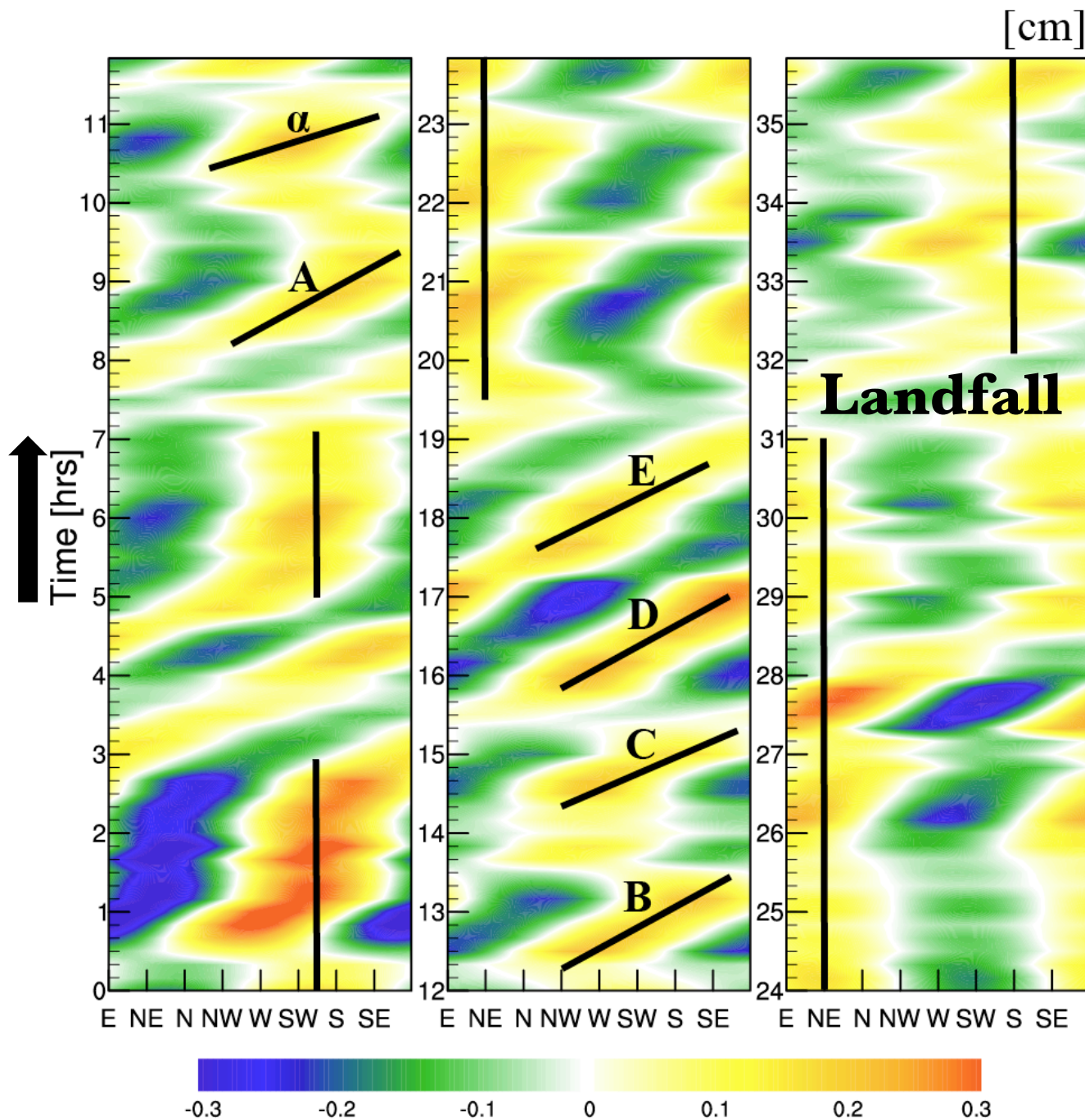
Precipitable  
water



Vertical and  
horizontal winds

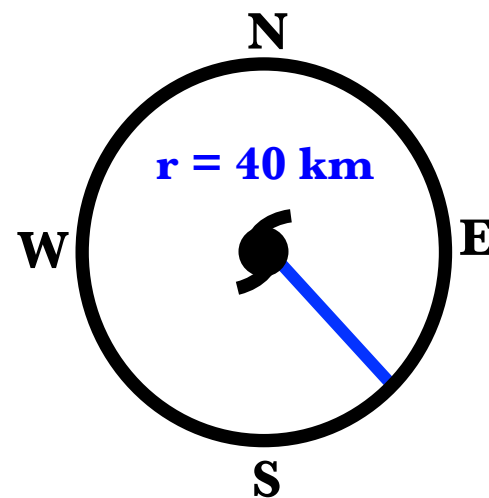


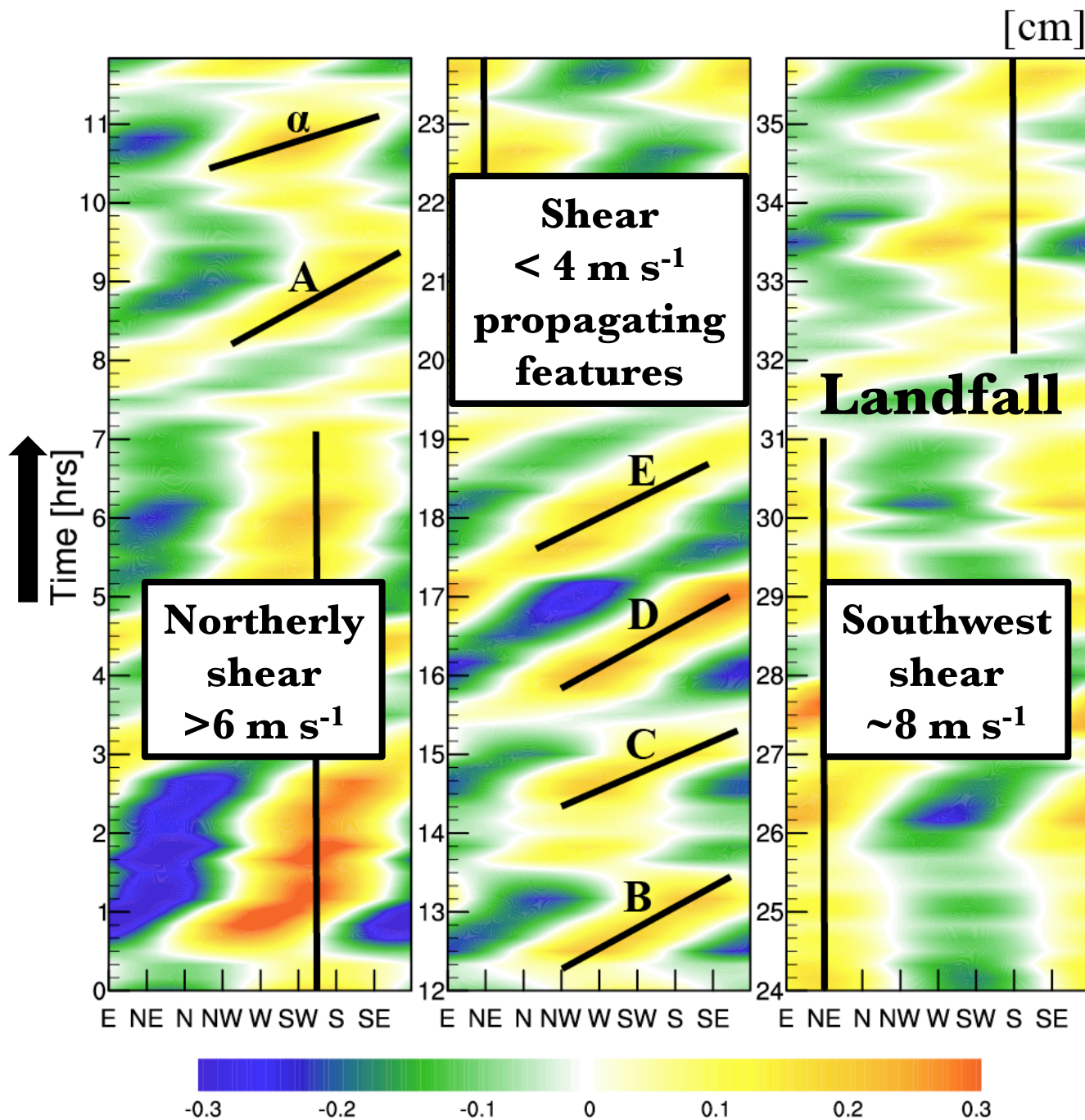
Potential  
vorticity



Azimuth-Time  
Hovmöller

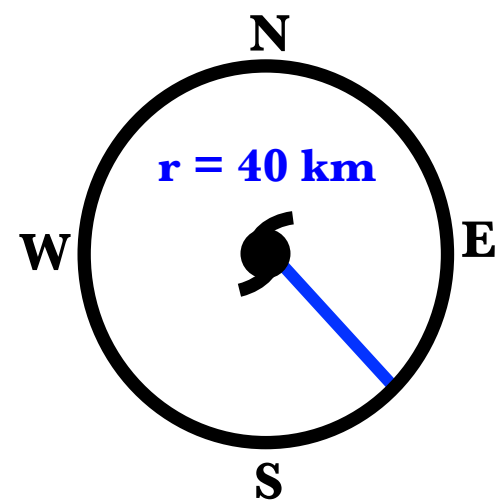
Wavenumber  
One  
Precipitable  
water





**Azimuth-Time**  
**Hovmöller**

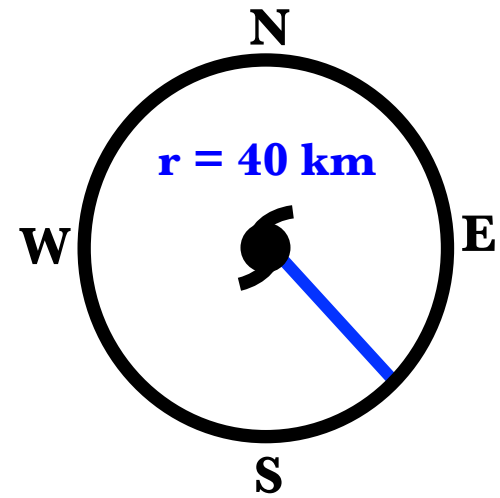
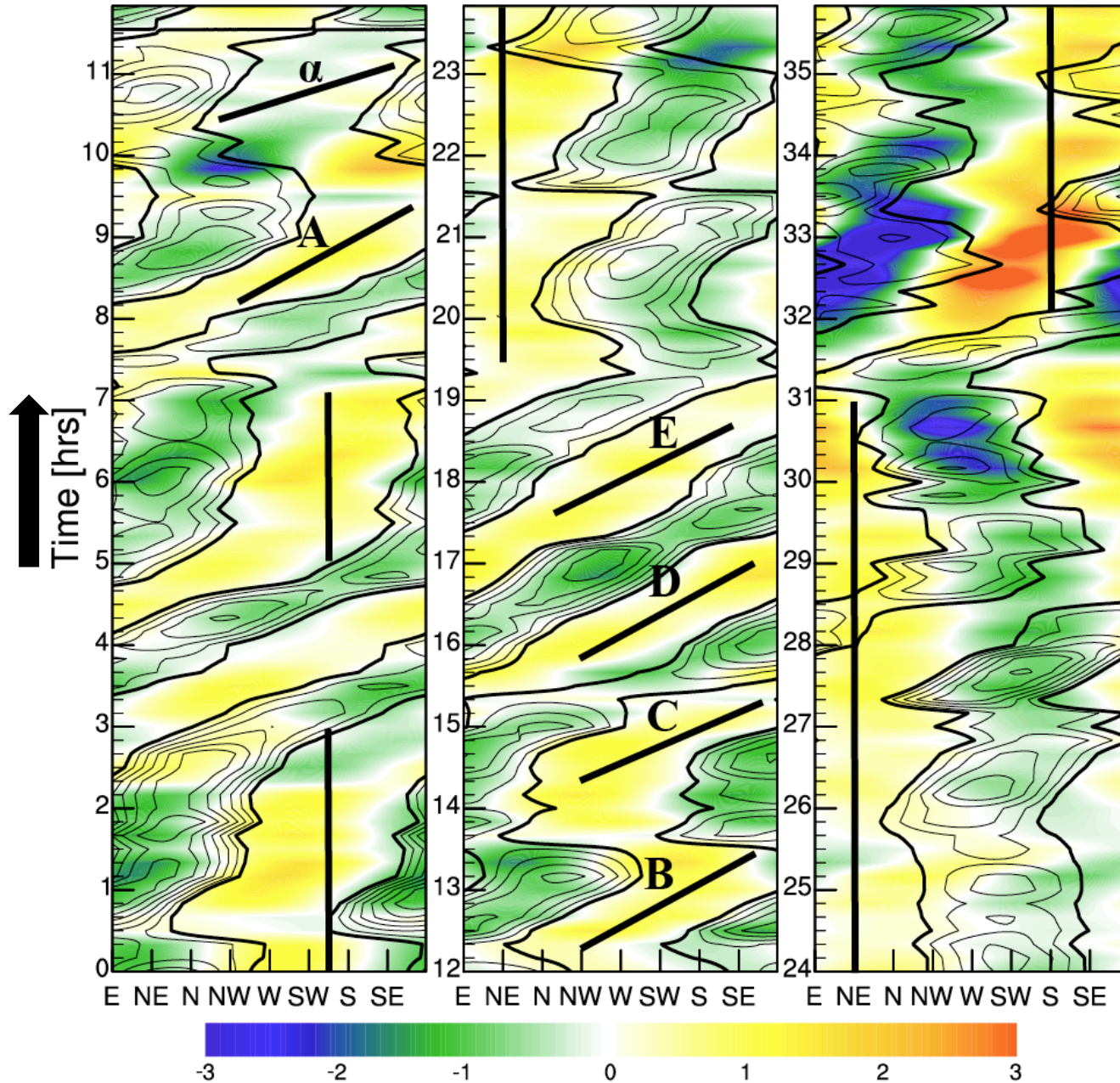
**Wavenumber**  
**One**  
**Precipitable**  
**water**



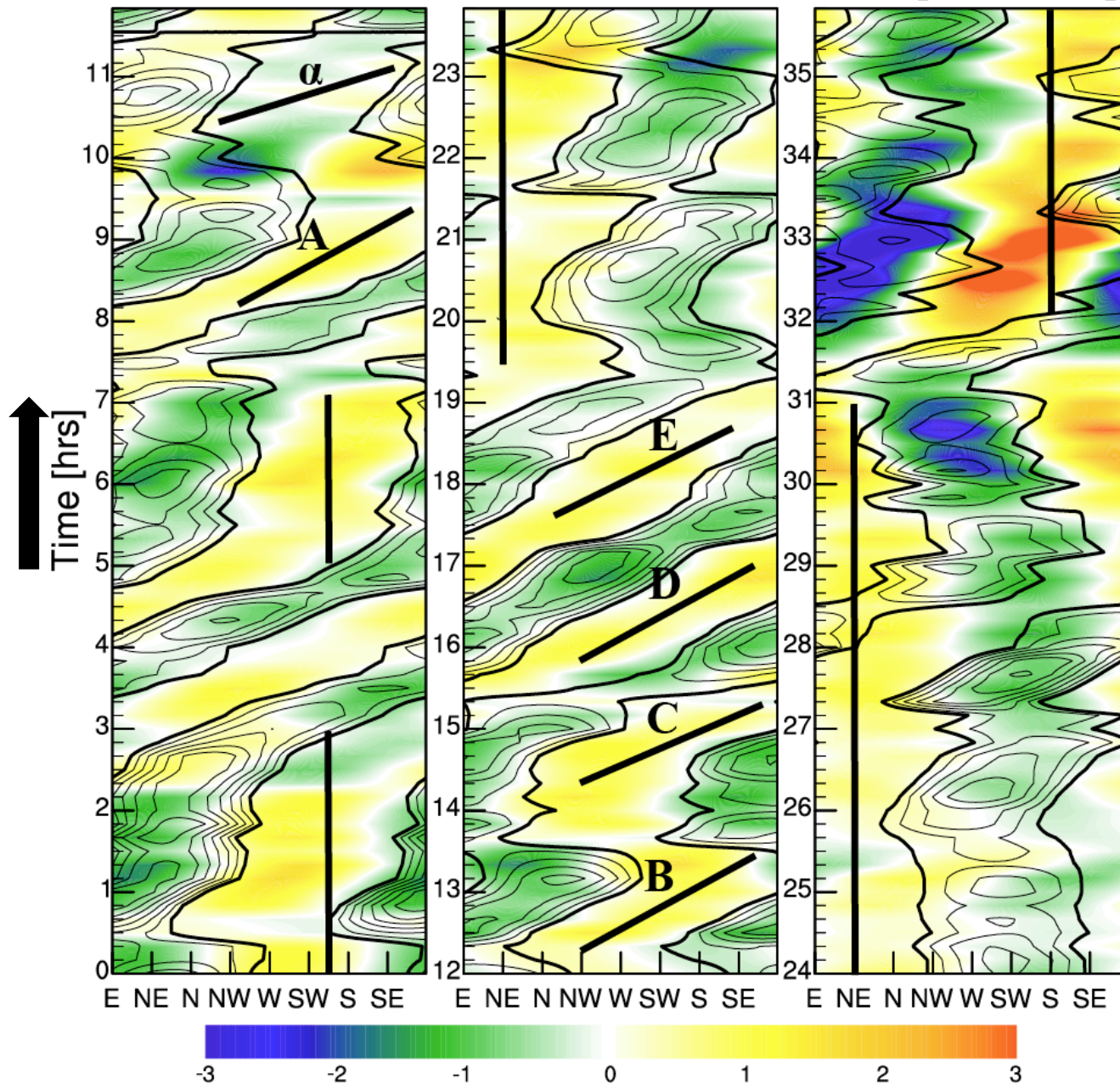
[PVU, cm]

# Azimuth-Time Hovmöller

Wavenumber  
One PV  
(shaded) and  
PW  
(contours)

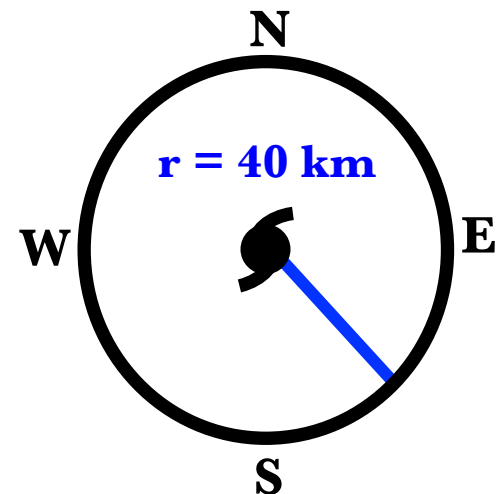


[PVU, cm]

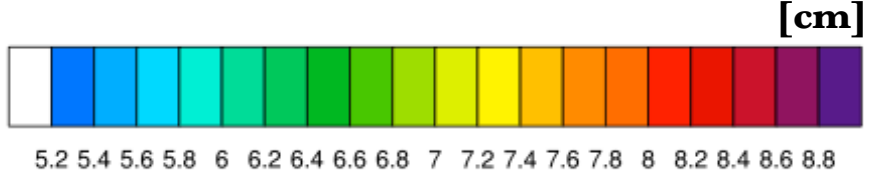
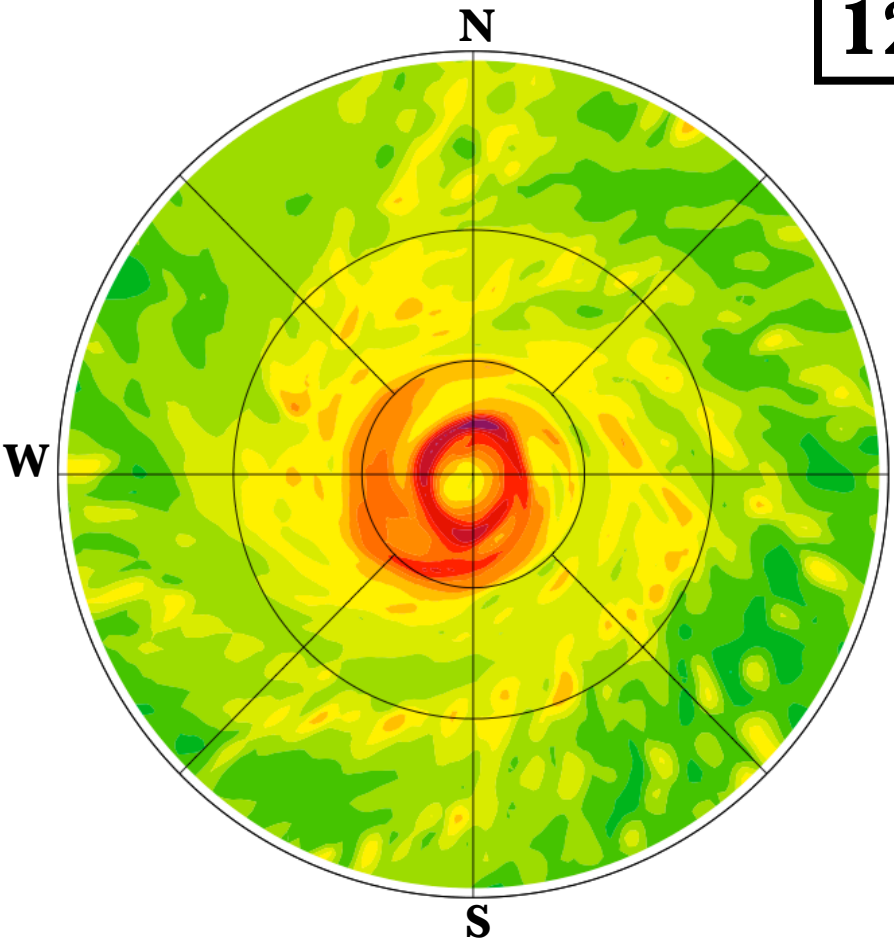


**Convectively  
coupled  
PV features**

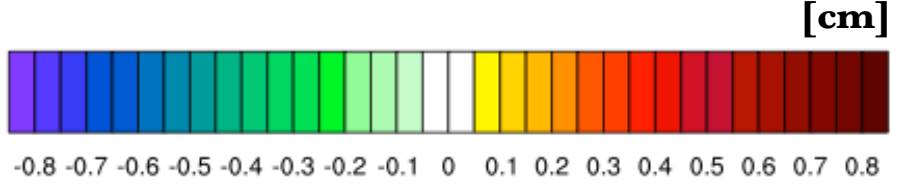
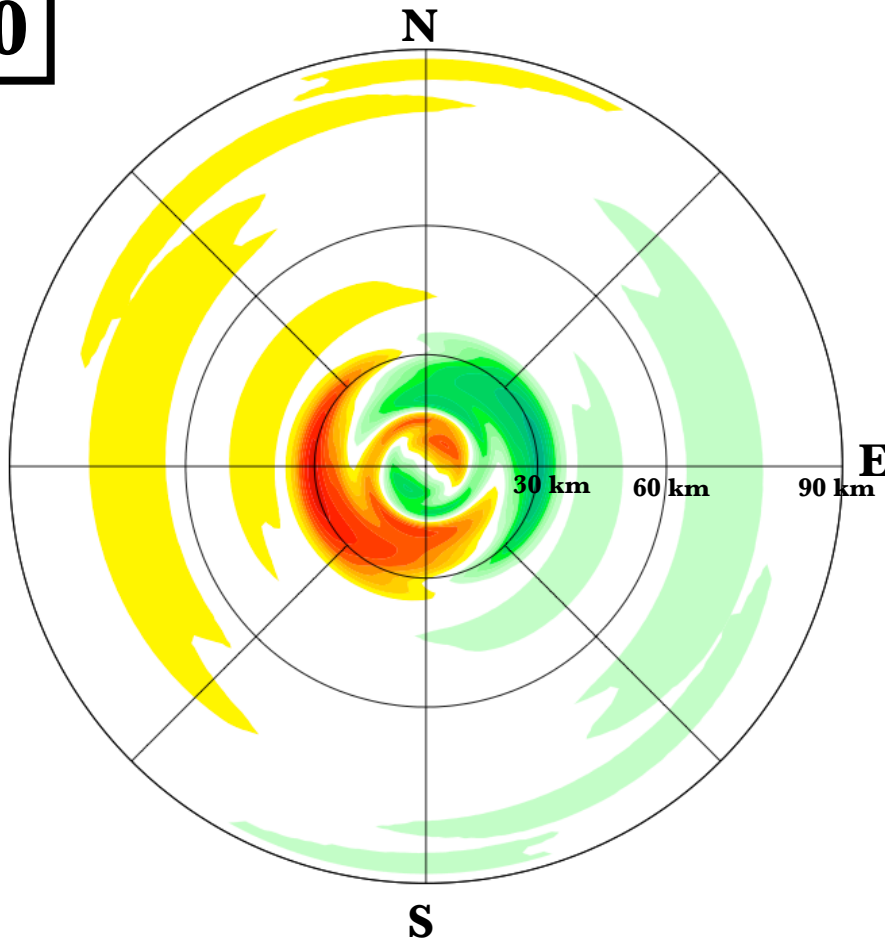
**Azimuthal  
phase speeds:  
 $32 - 38 \text{ m s}^{-1}$   
 $74 - 84\% \text{ of } V_T$**



**12:10**

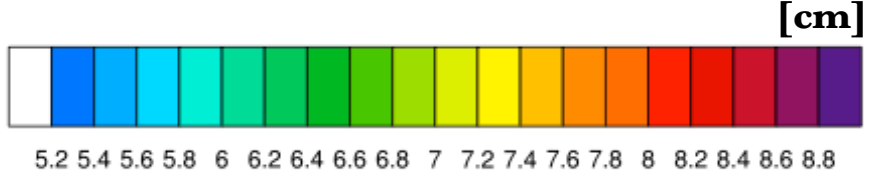
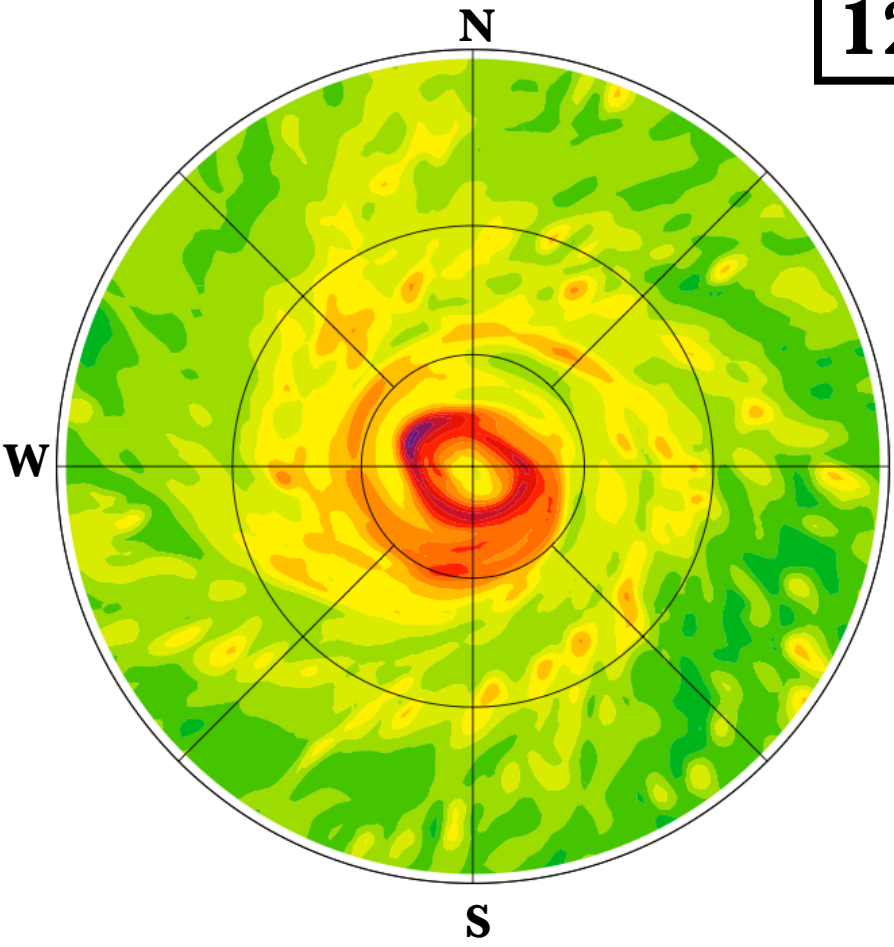


**Precipitable water**

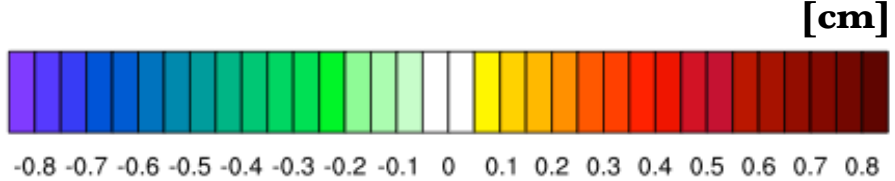
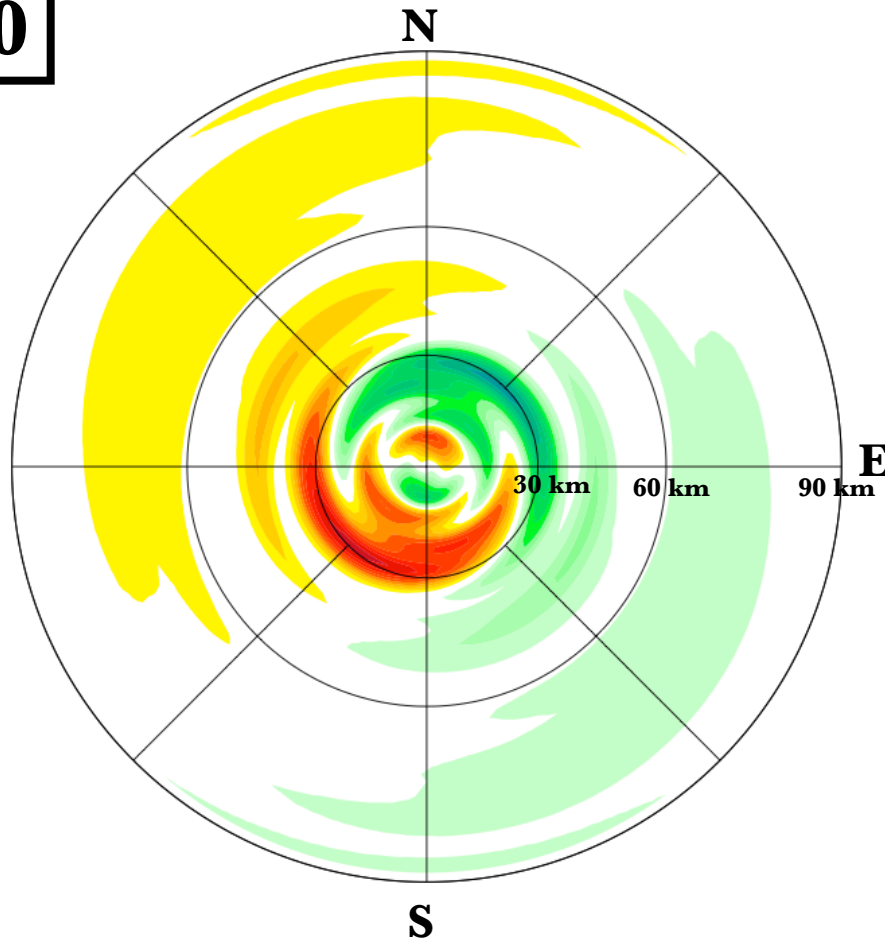


**Wavenumber 1**  
**Precipitable water**

**12:20**

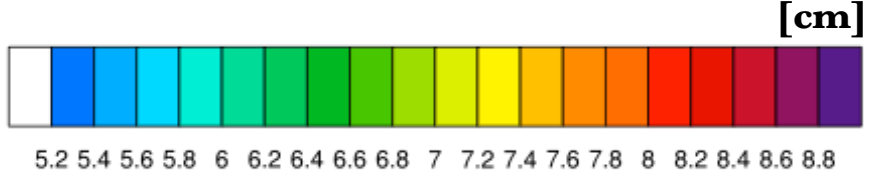
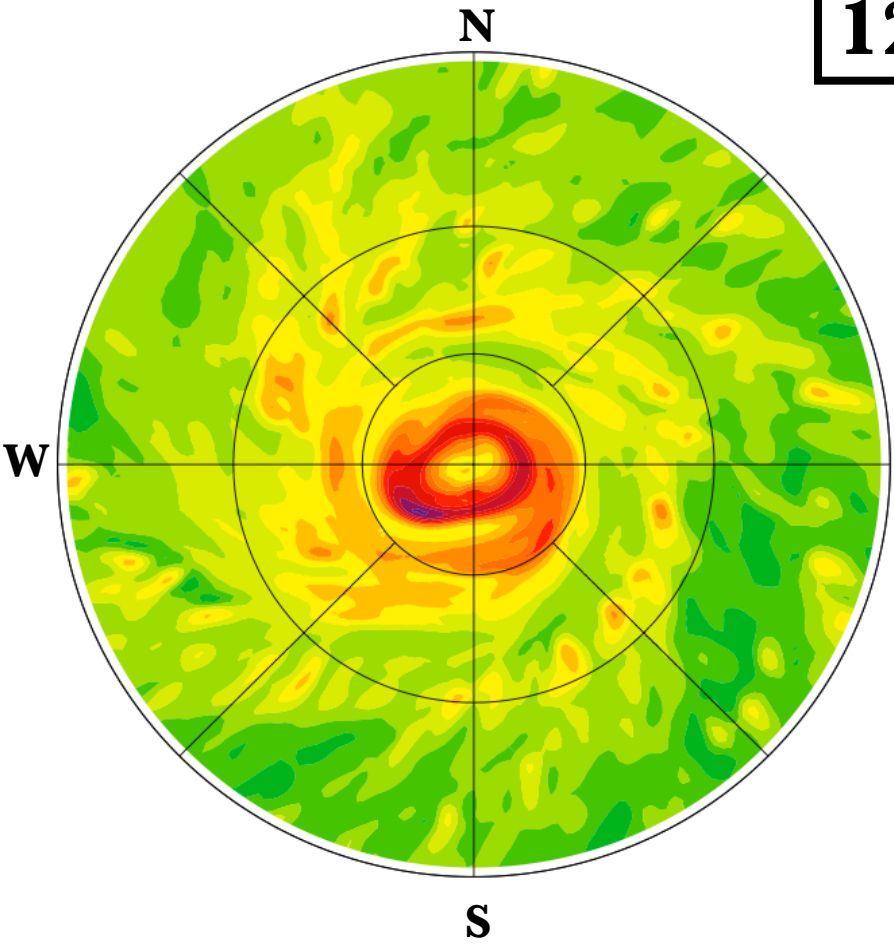


**Precipitable water**

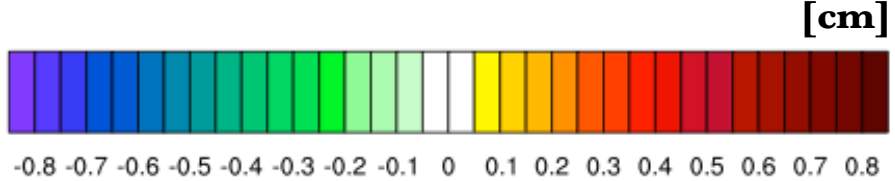
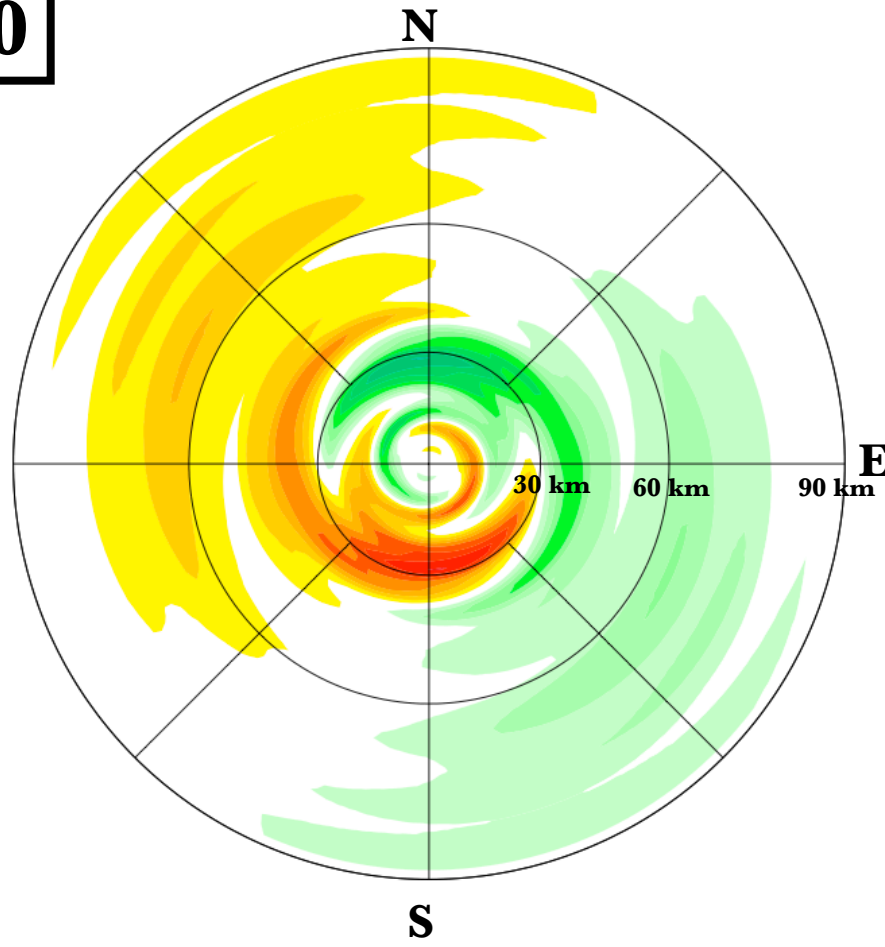


**Wavenumber 1**  
**Precipitable water**

**12:30**

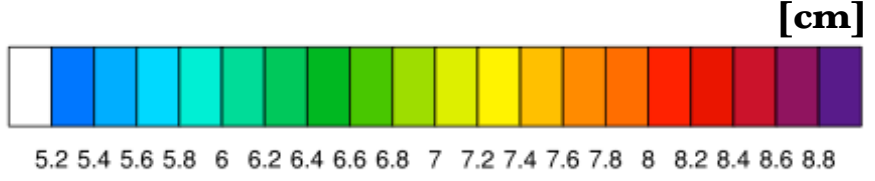
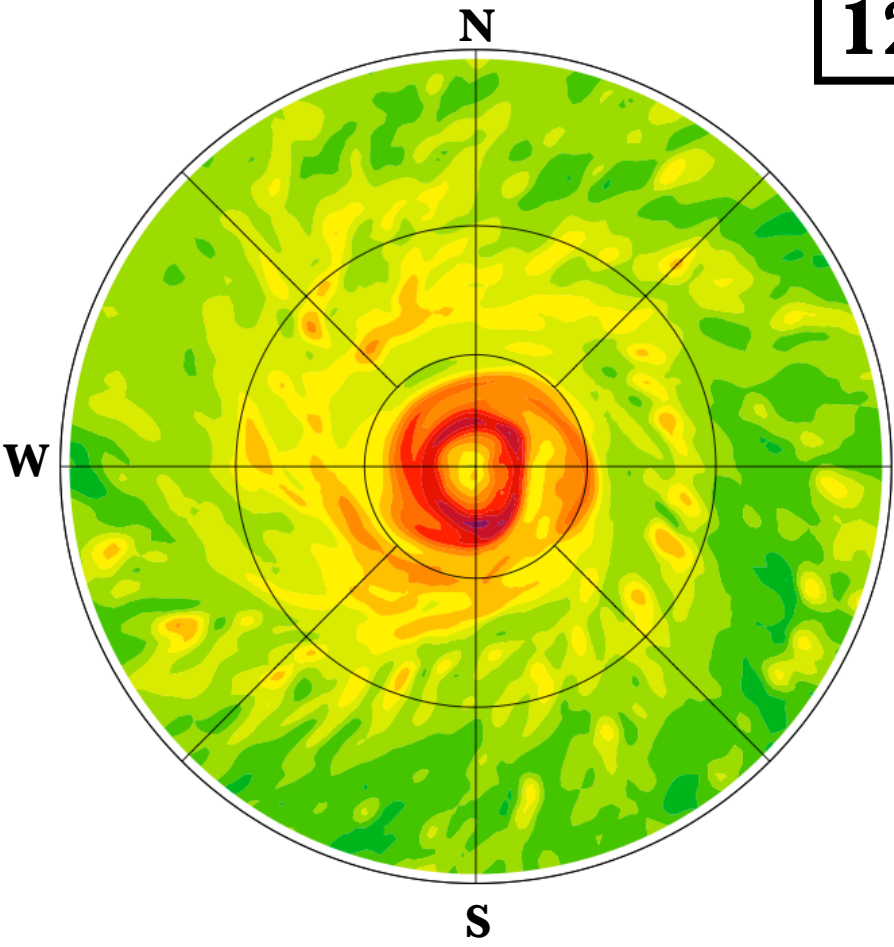


**Precipitable water**

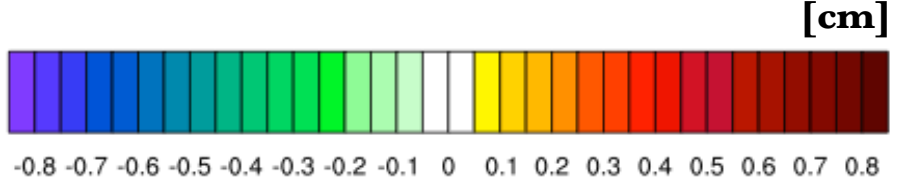
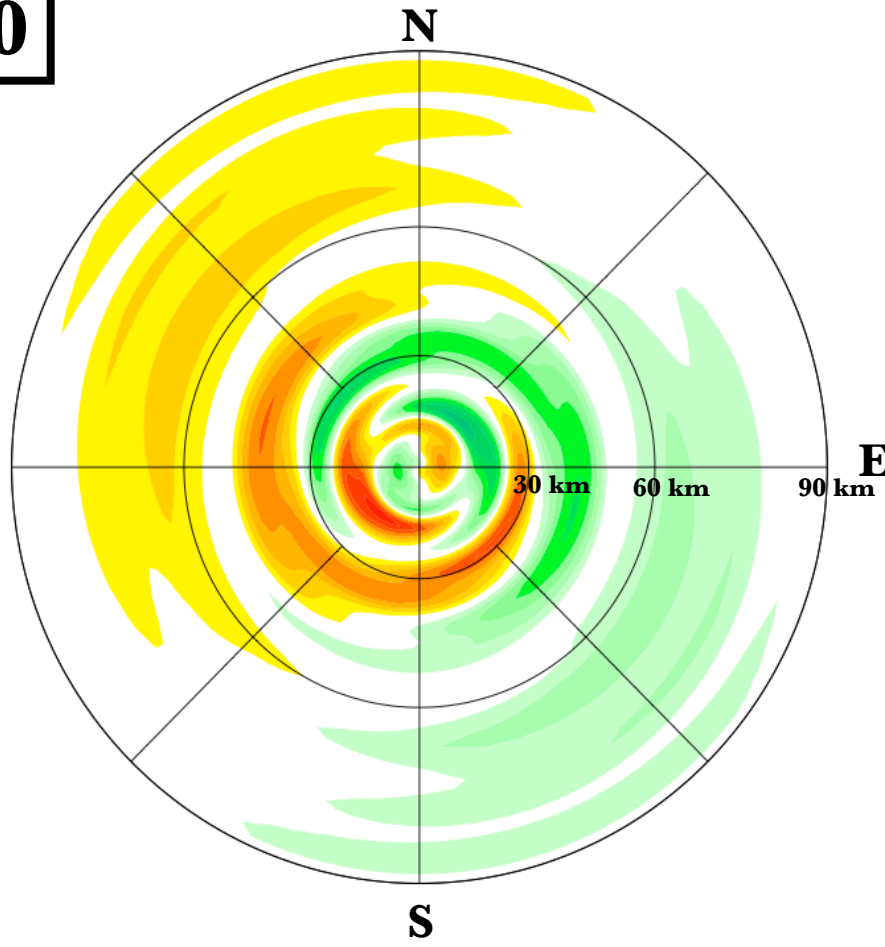


**Wavenumber 1**  
**Precipitable water**

**12:40**

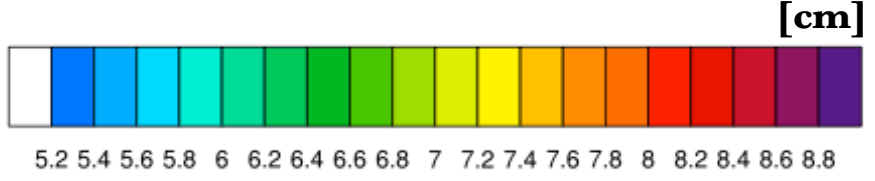
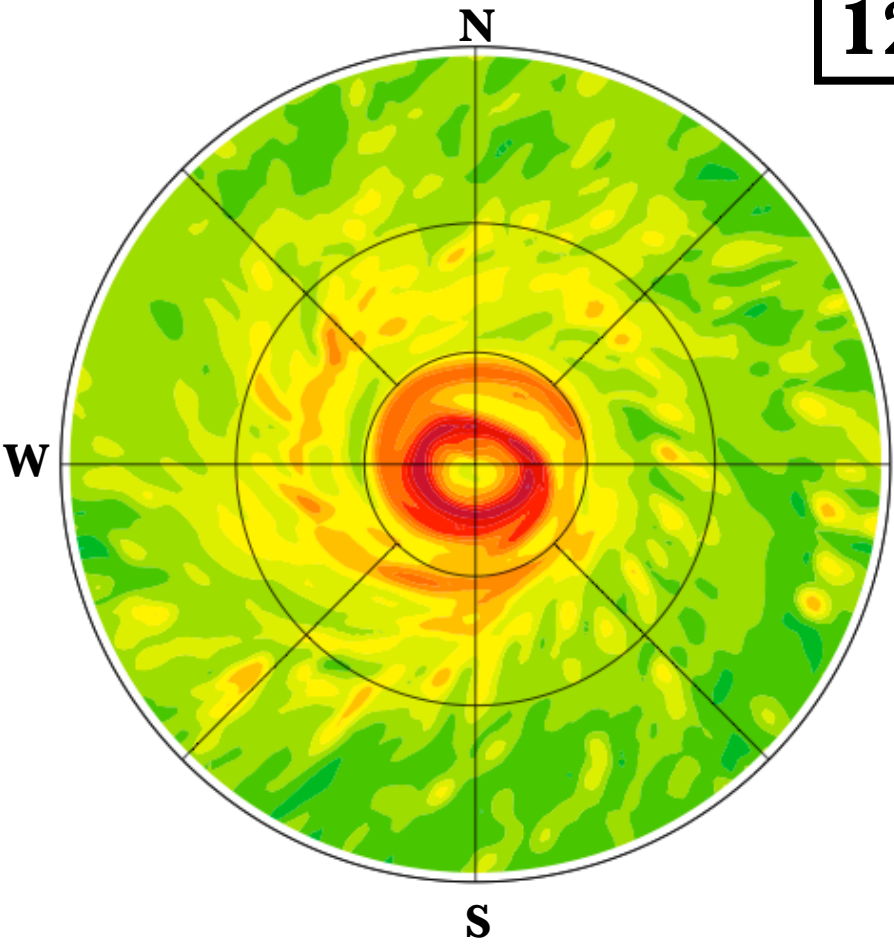


**Precipitable water**

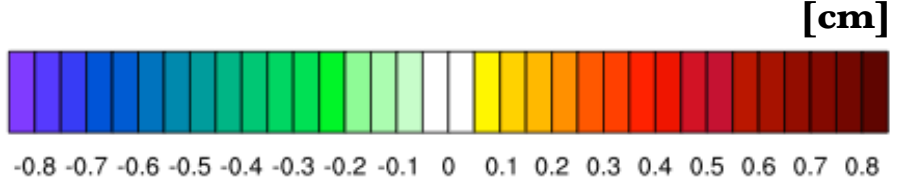
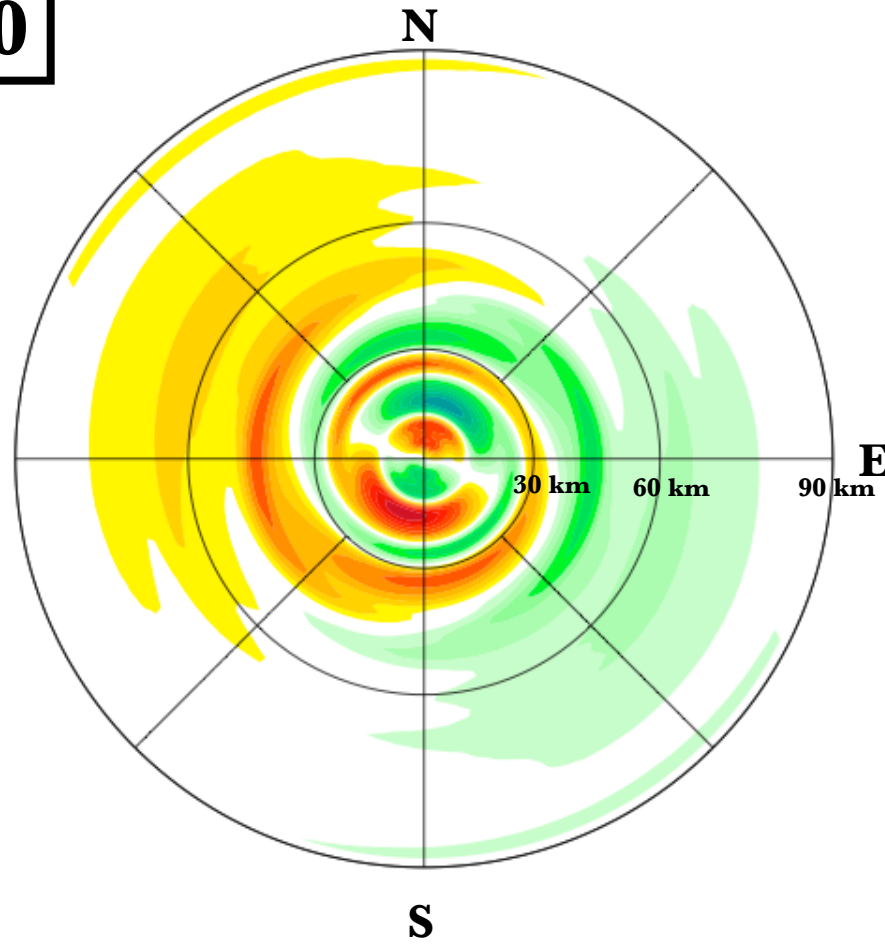


**Wavenumber 1**  
**Precipitable water**

**12:50**

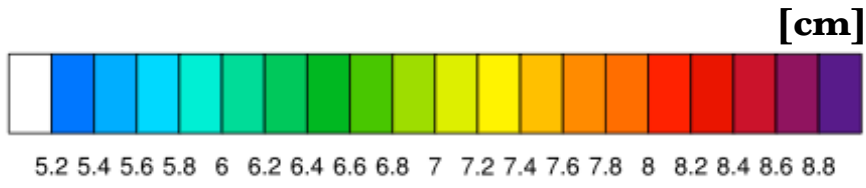
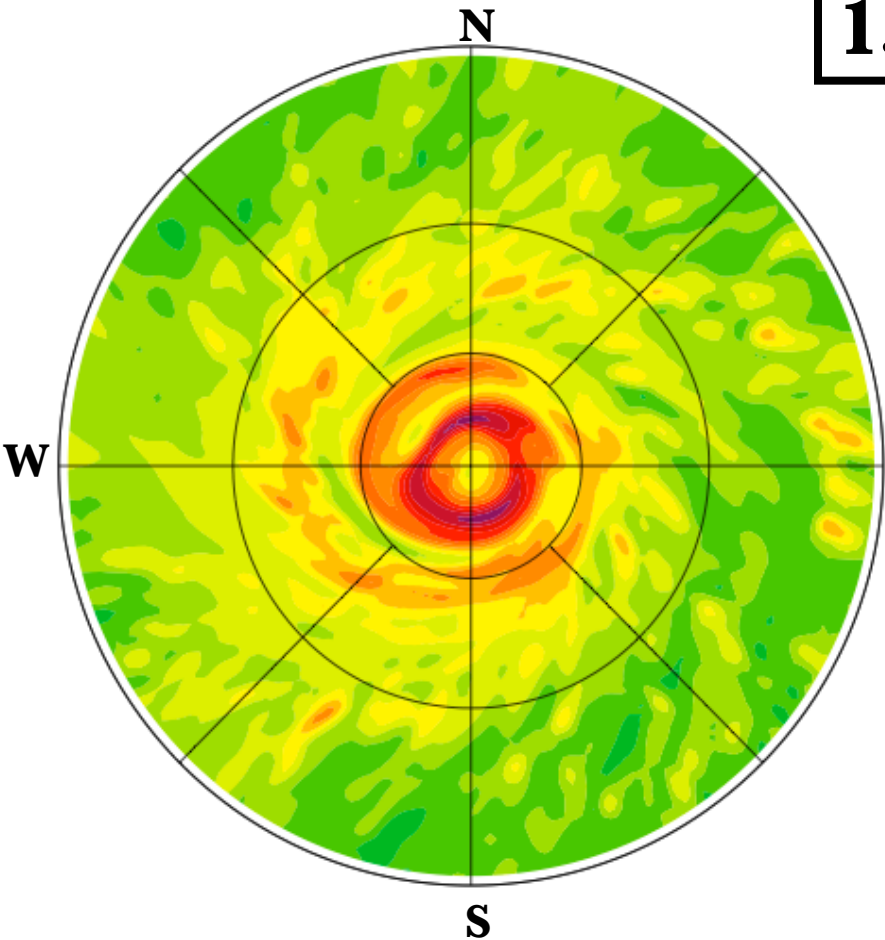


**Precipitable water**

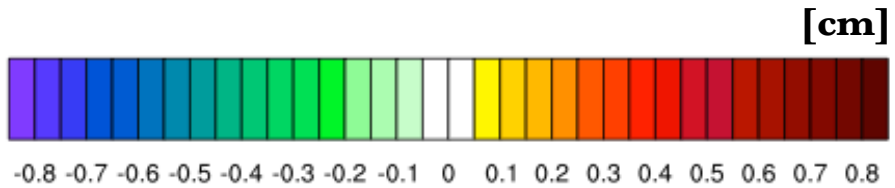
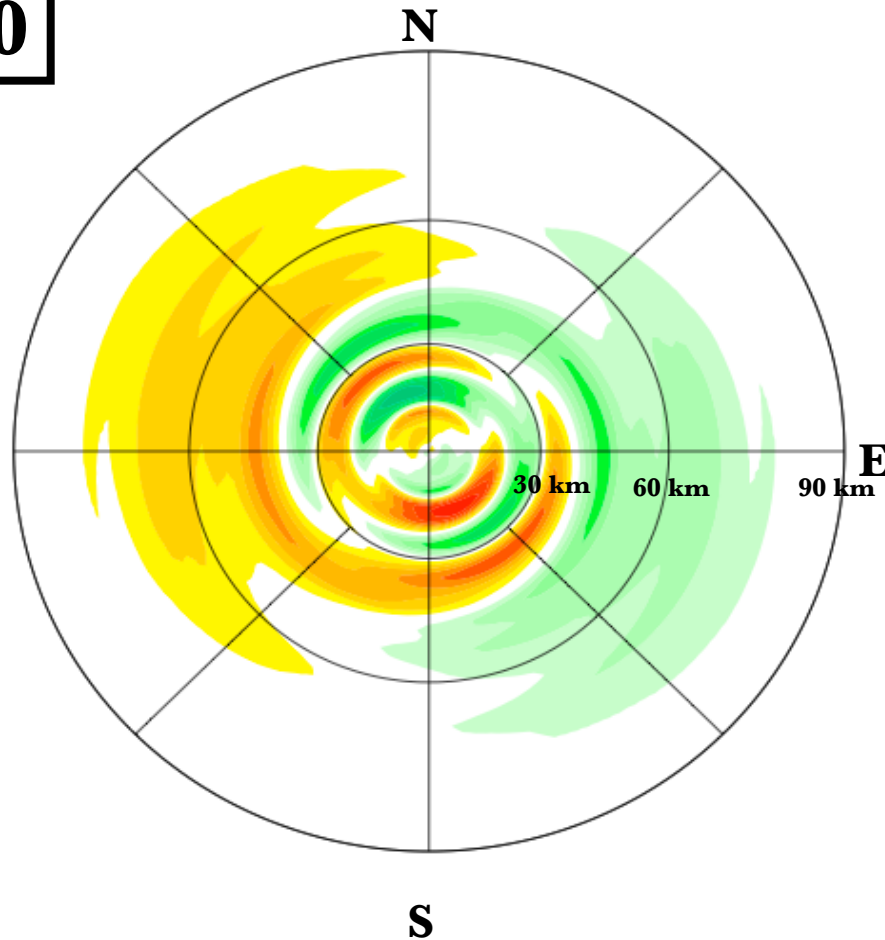


**Wavenumber 1**  
**Precipitable water**

**13:00**

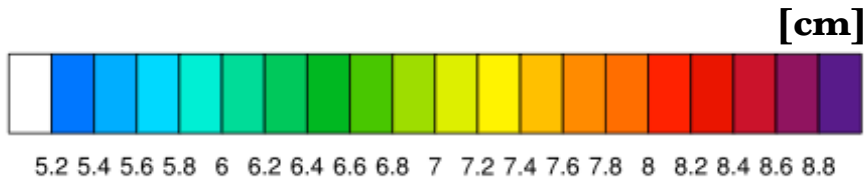
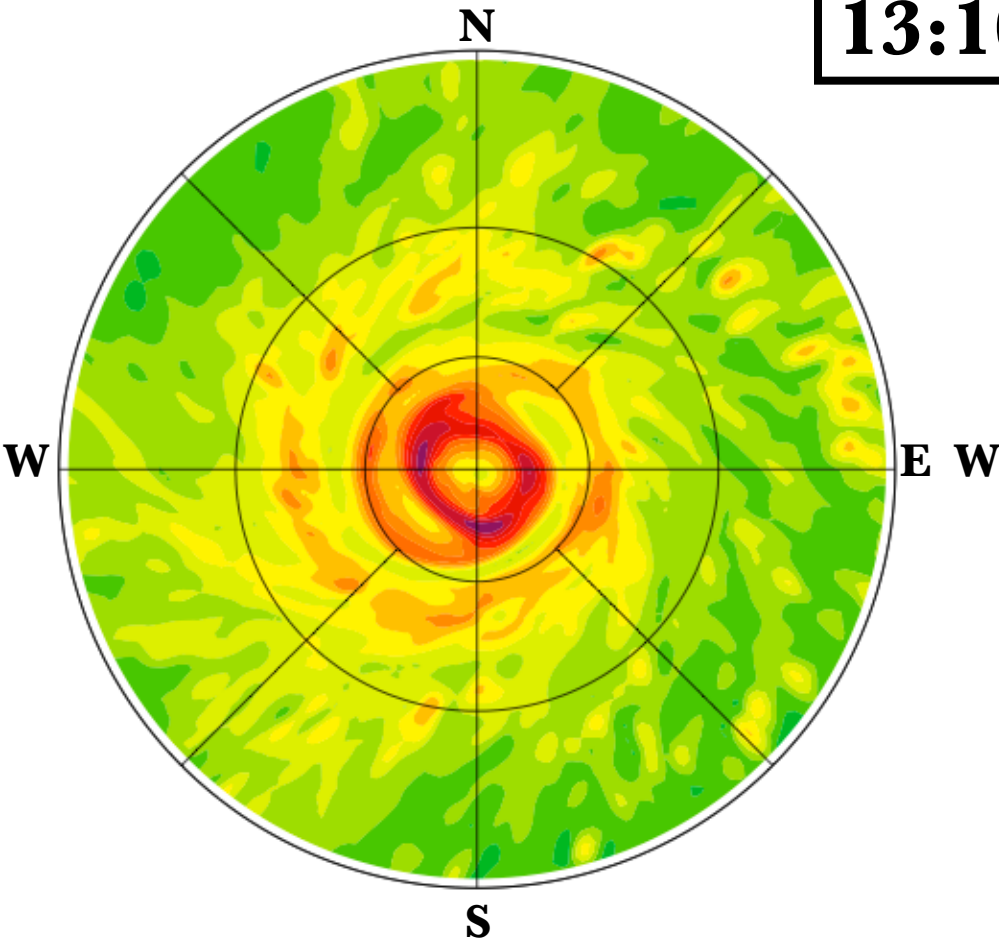


**Precipitable water**

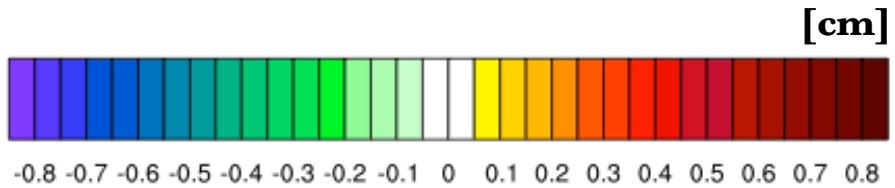
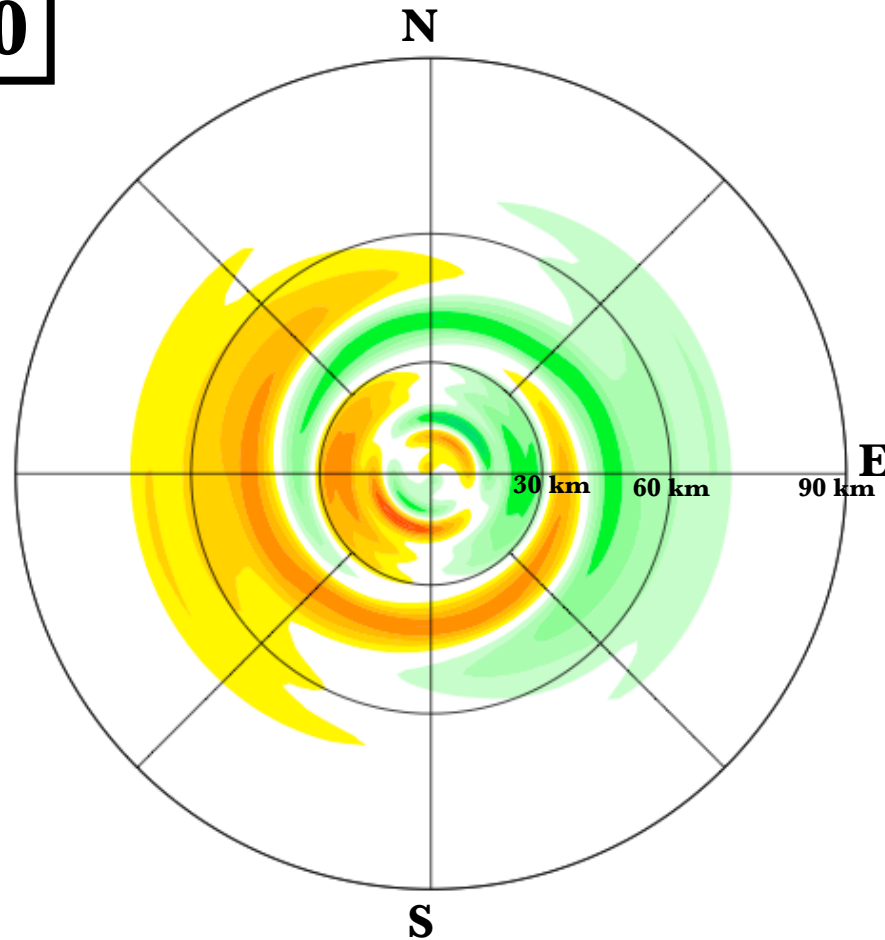


**Wavenumber 1**  
**Precipitable water**

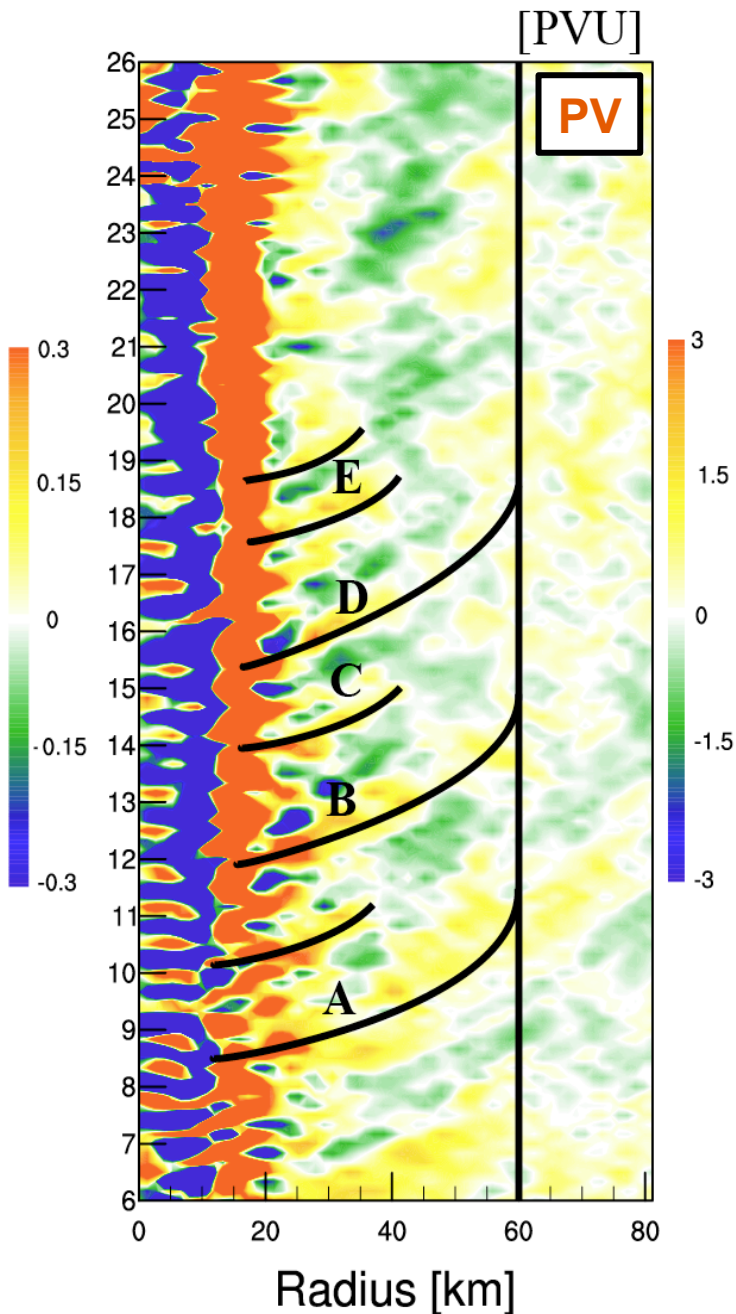
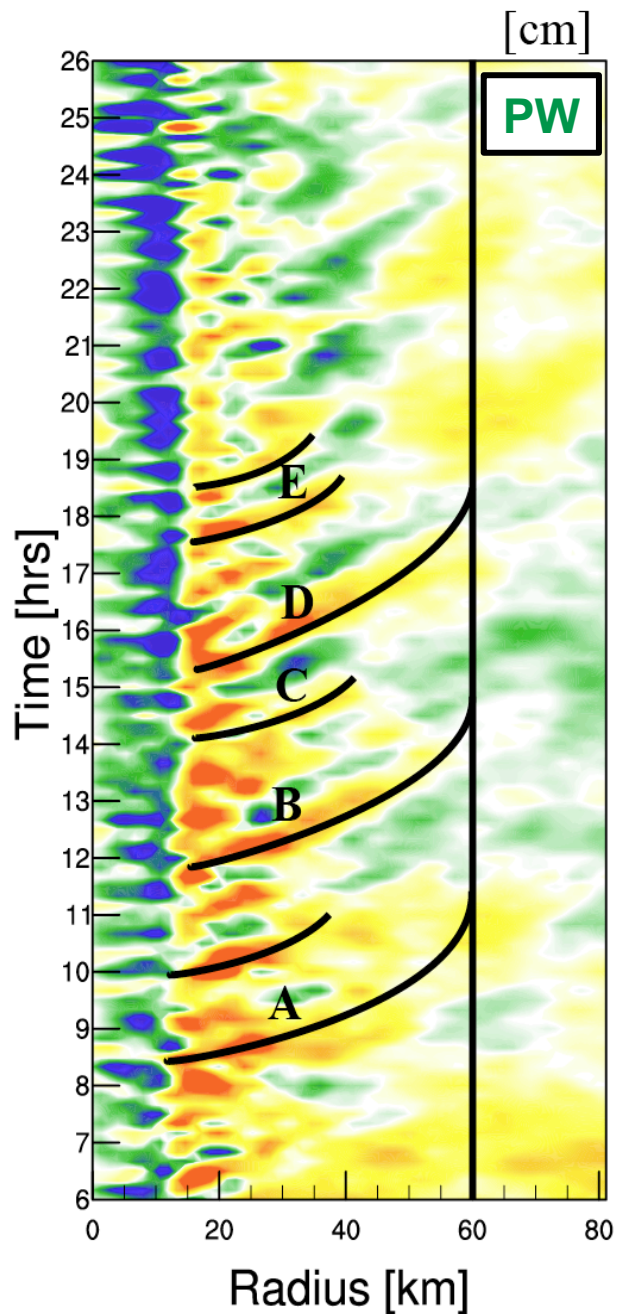
**13:10**



**Precipitable water**



**Wavenumber 1**  
**Precipitable water**



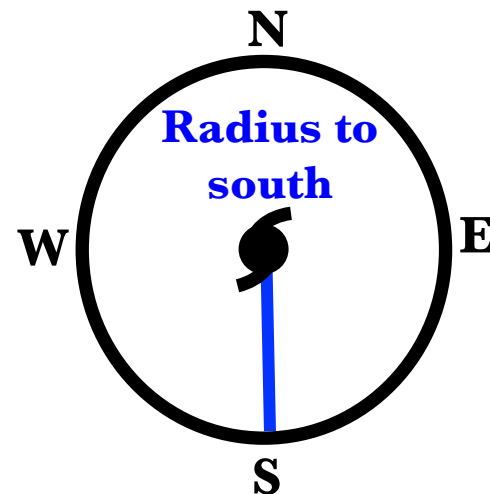
# Radius-Time Hovmöller

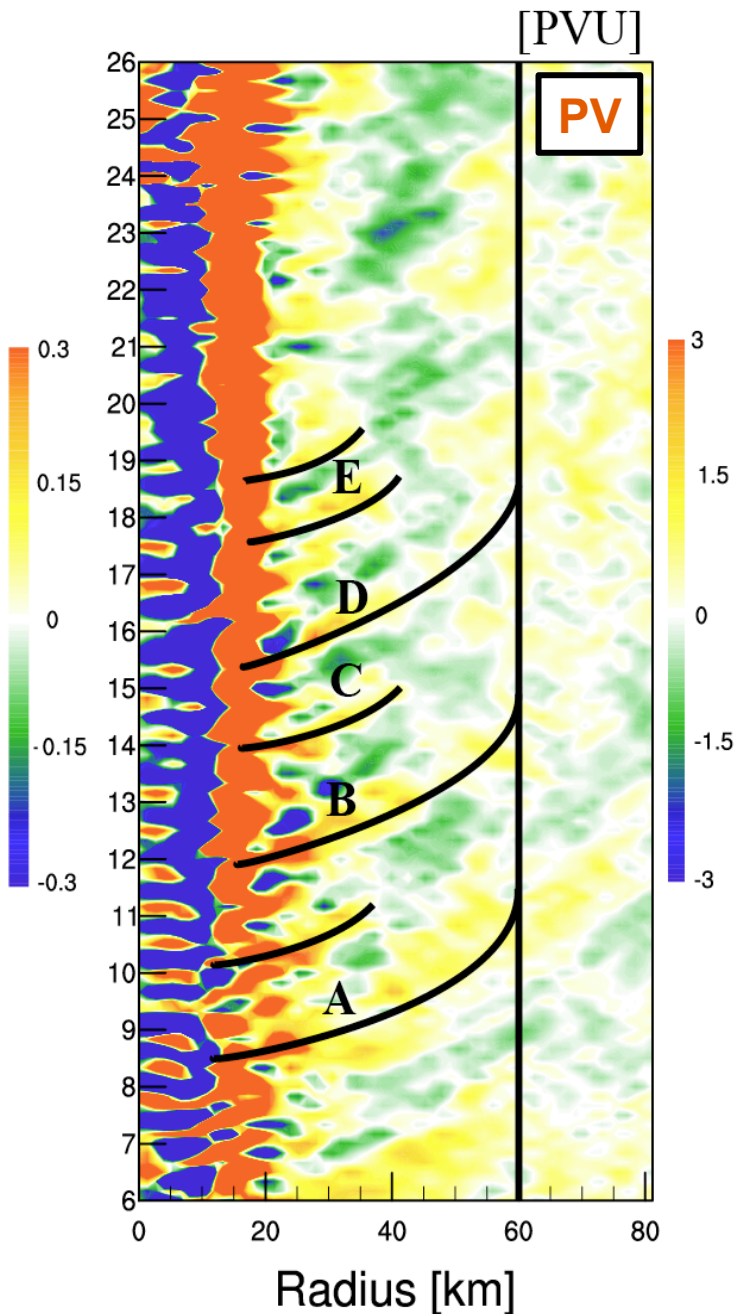
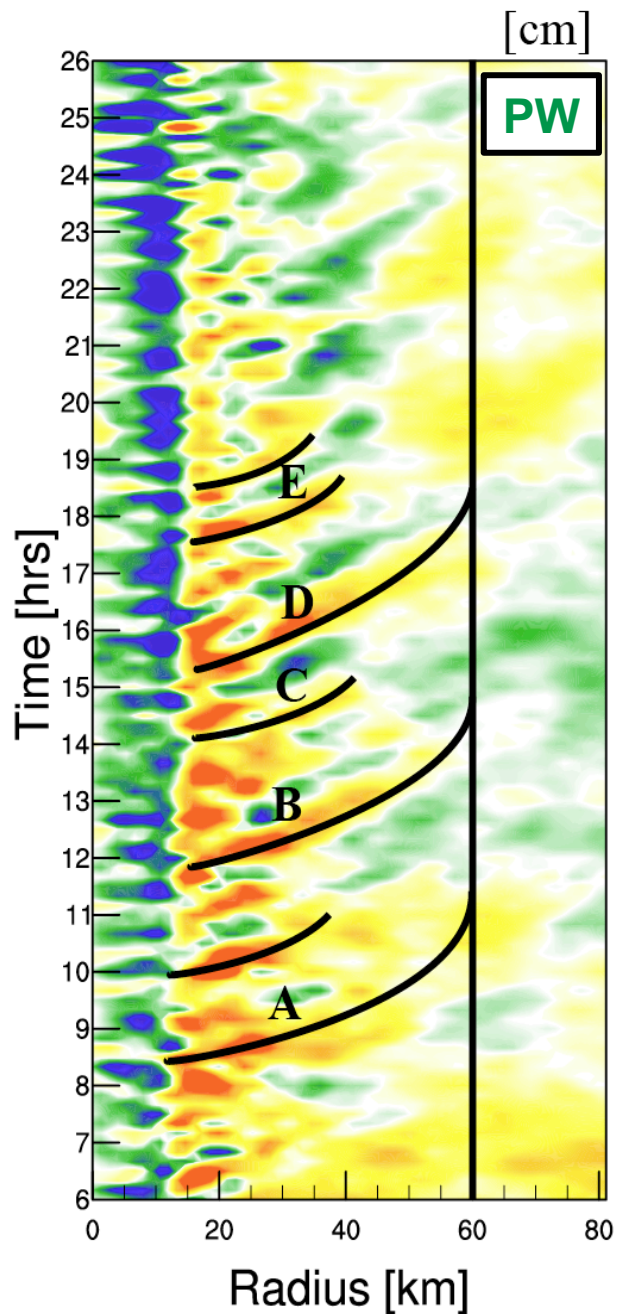
## Wavenumber

One

PW (left) and

PV (right)

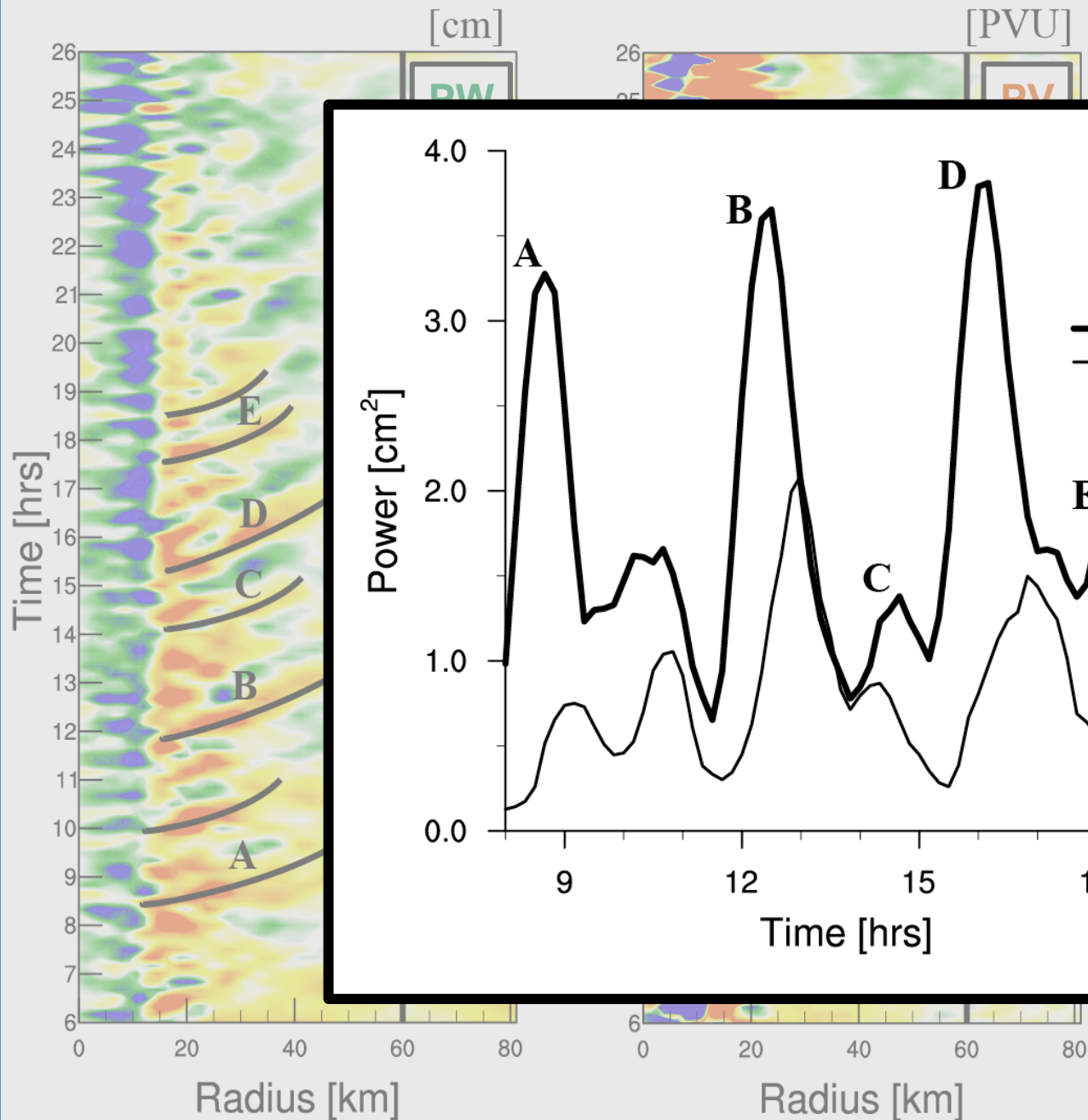




**Features**  
**propagate**  
**outward**  
 $\sim 5 \text{ m s}^{-1}$

**Evidence of**  
**vortex Rossby**  
**wave**  
**stagnation**  
**radius**

$\sim$  **3** x **radius** of  
**maximum**  
**wind**



## Features

propagate

outward

$5 \text{ m s}^{-1}$

presence of

x Rossby

wave

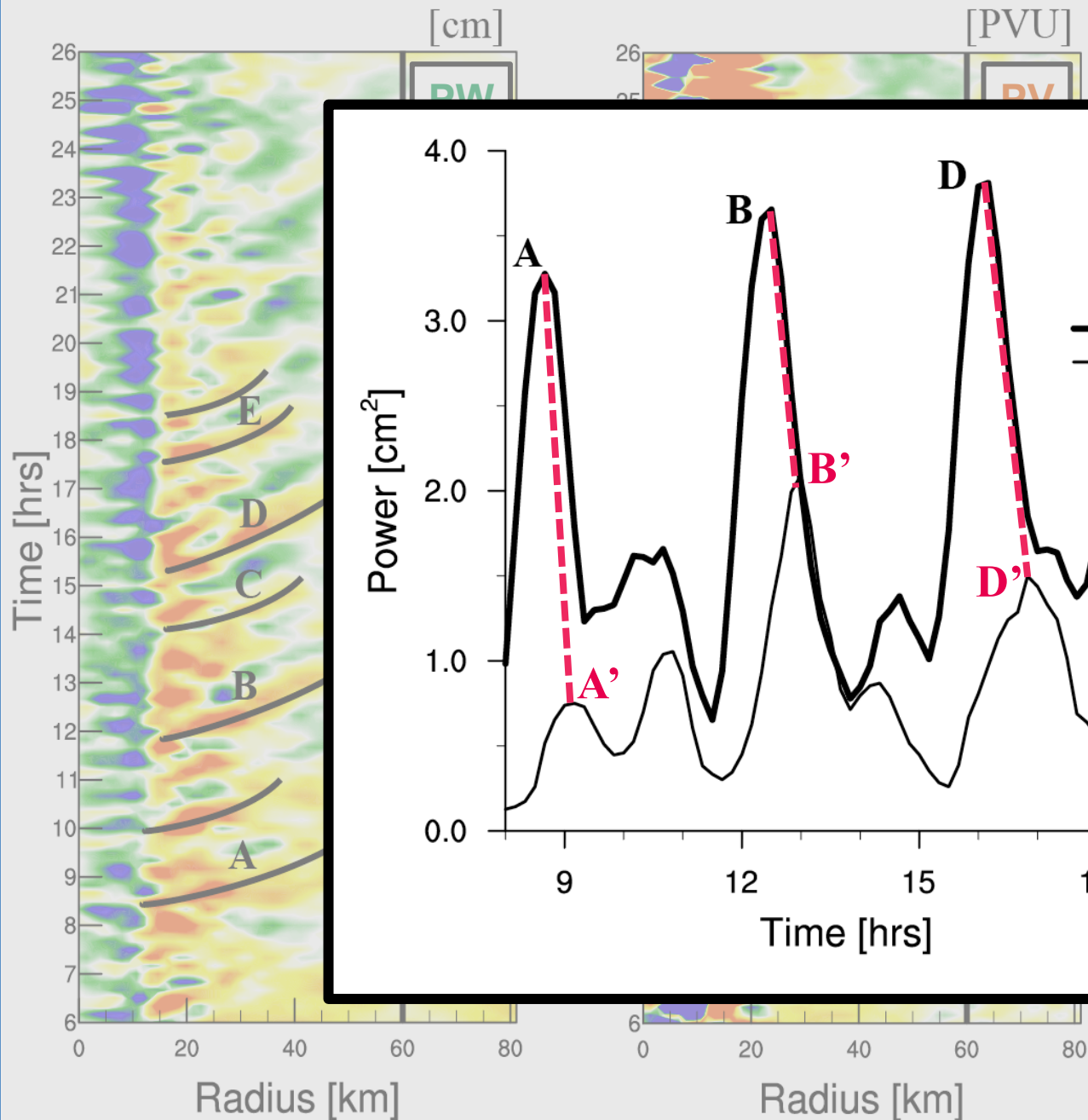
generation

radius

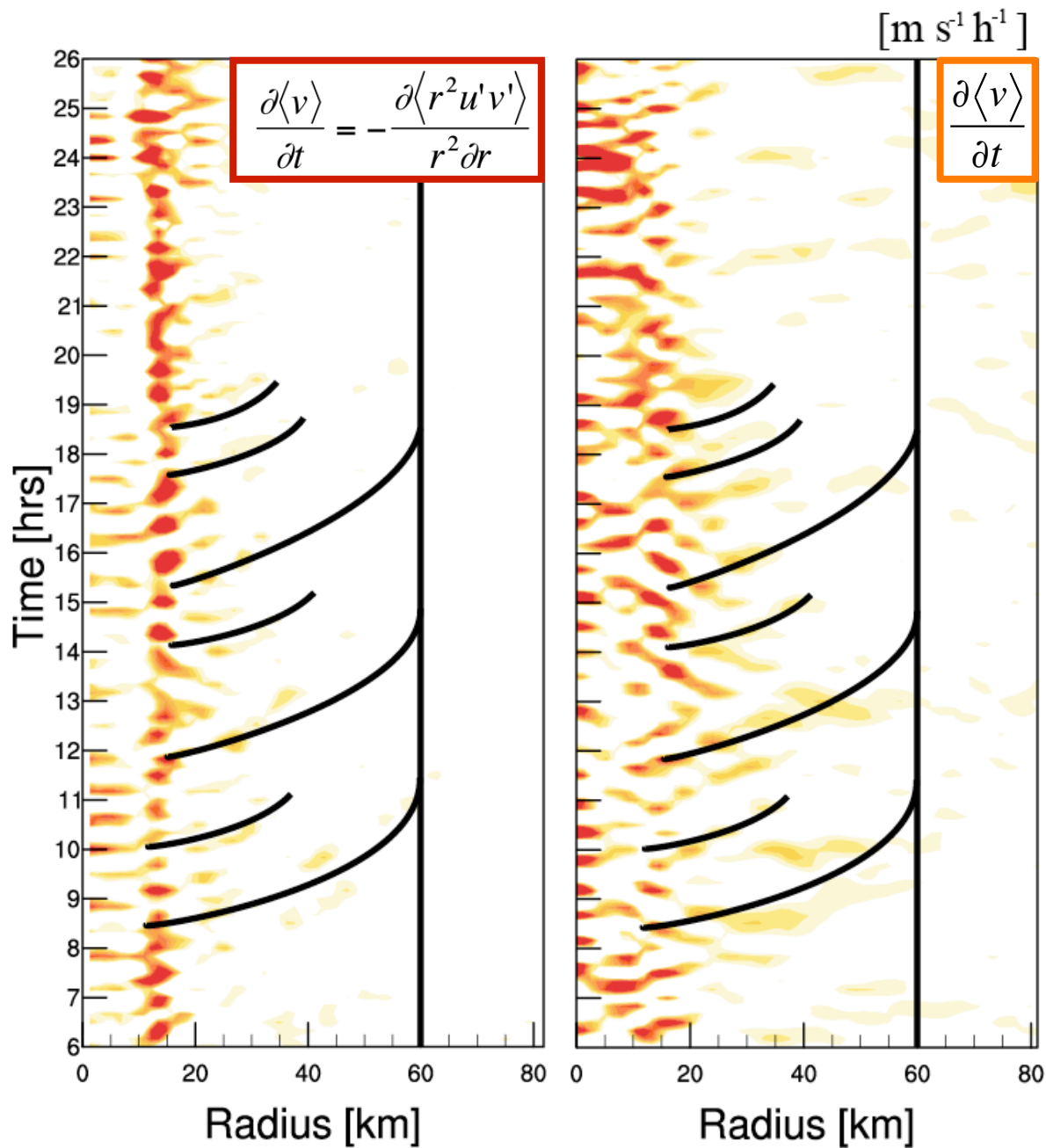
radius of

maximum

wind



Features  
 propagate  
 outward  
 $5 \text{ m s}^{-1}$   
 presence of  
 Rossby  
 wave  
 generation  
 radius  
 radius of  
 maximum  
 wind

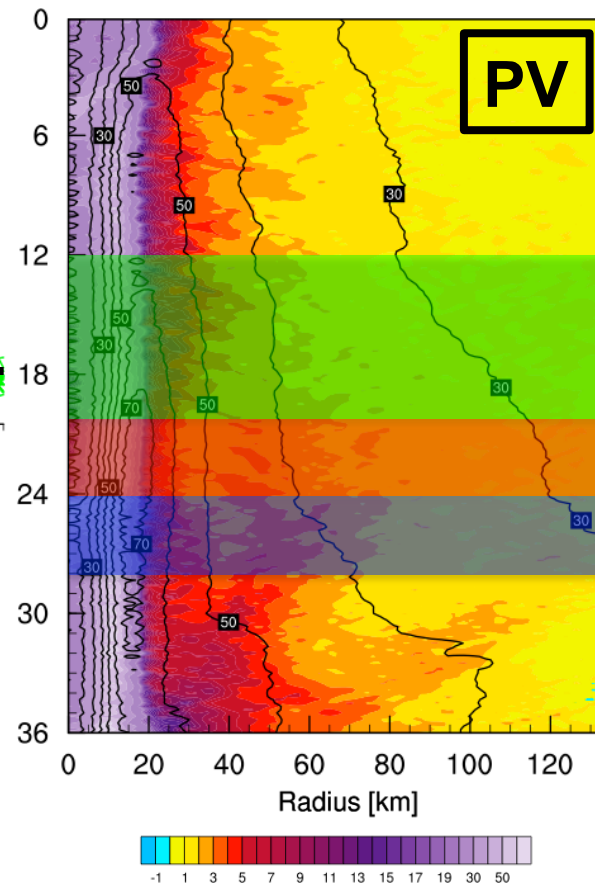
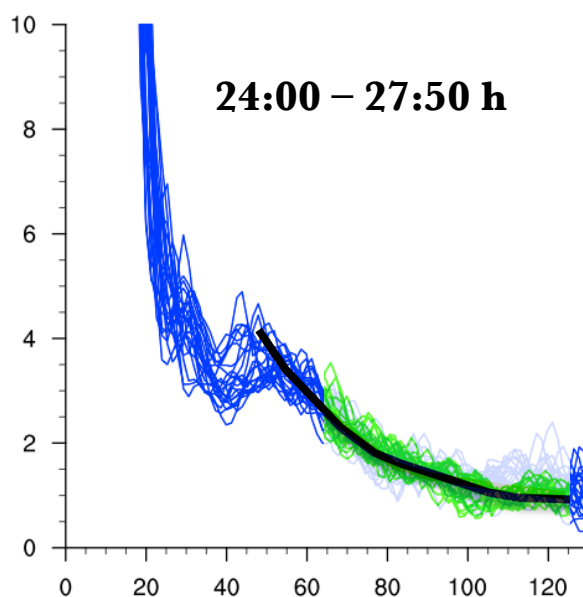
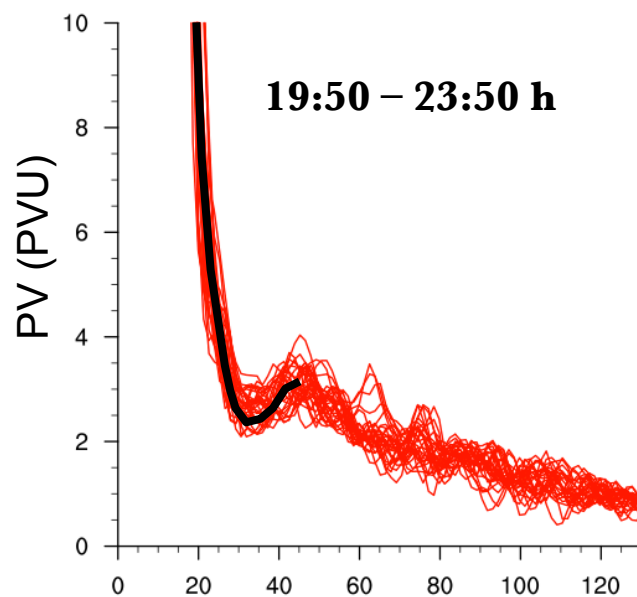
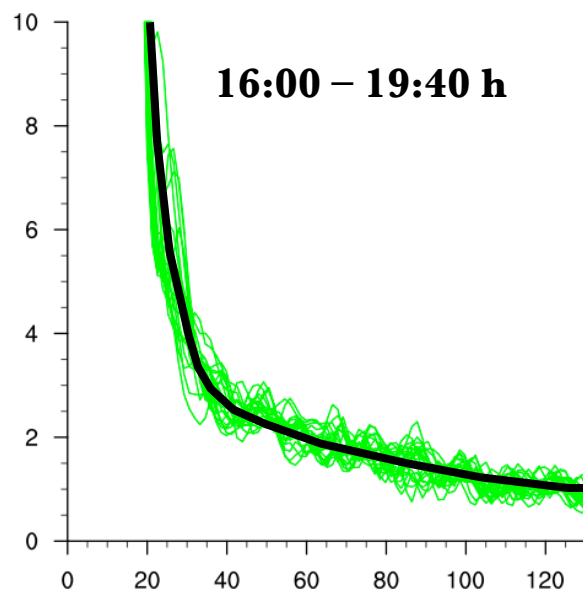
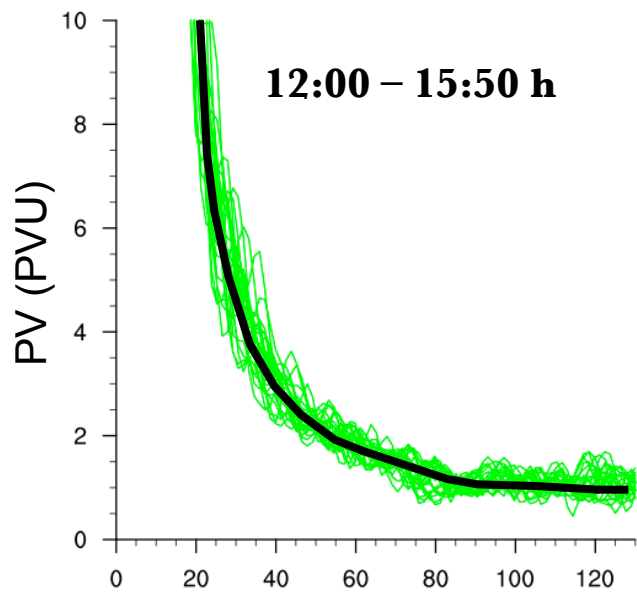


# Radius-Time Hovmöller

**Azimuthally  
averaged  
850 hPa**

**Eddy  
momentum flux  
divergence (left)**

**Tangential wind  
acceleration  
(right)**



Radius (km)

# **Summary, Conclusions and Future Work**

- **Advanced Hurricane WRF simulation of Katrina (2005) underwent secondary eyewall formation (SEF) with (some) characteristics observed in nature**
- **SEF is related to the axisymmetrization of inner spiral rainbands that propagate outward and stagnate at a radius  $\sim 3$  times the RMW**
- **Inner spiral rainbands are vortex Rossby waves generated through barotropic instability**
- **Examine null cases with high VRW activity and no SEF; explore environmental factors with the AHW EnKF system *{see poster 2.31 on Wednesday}***