Coupling of Precipitation and the Associated Cloud Organization to Moisture Transport in Extratropical Cyclones

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$$P - E + \frac{\partial Q}{\partial t} = -Q\nabla \cdot \vec{V} - \vec{V} \cdot \nabla Q$$

QCNVG

QADVT

$$where$$

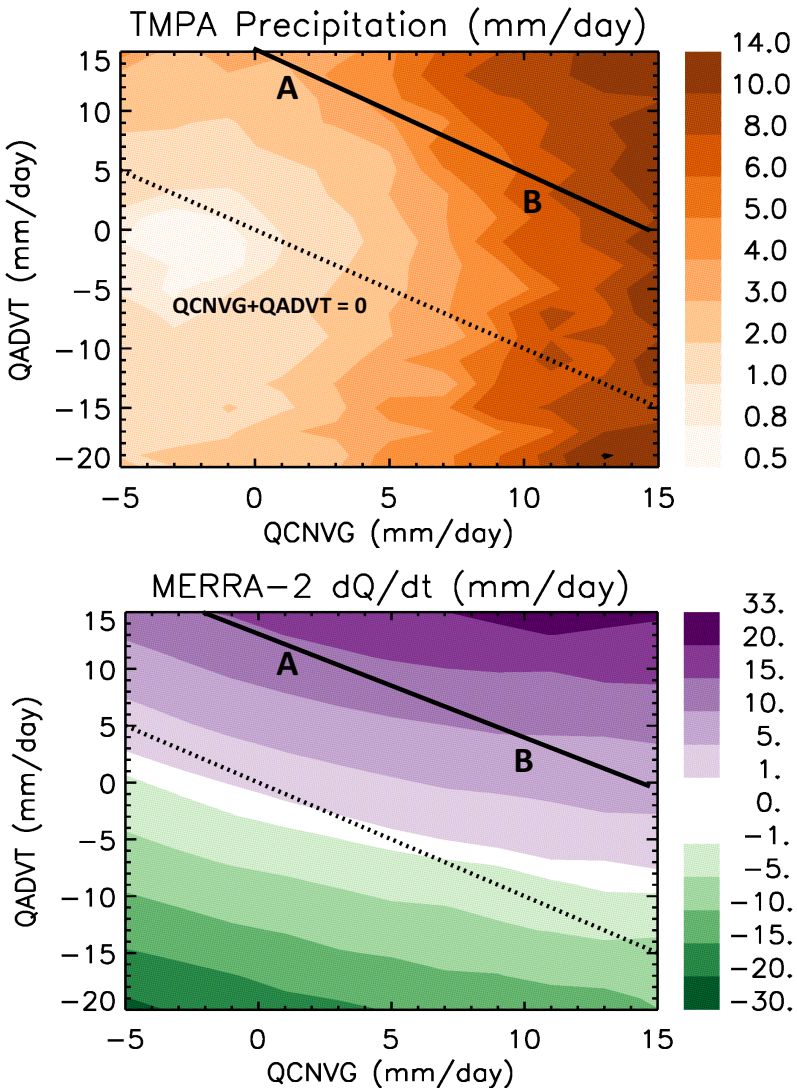
$$Q = \int_{ptop}^{psrf} q \frac{dp}{g}$$

$$\vec{V} = \frac{1}{Q} \int_{ptop}^{psrf} (q\vec{v}) \frac{dp}{g}$$

P: Precipitation

E: Evaporation

(Wong et al. 2016 J. Climate)



$$P - E + \frac{\partial Q}{\partial t} = -Q\nabla \cdot \vec{V} - \vec{V} \cdot \nabla Q$$

QCNVG

QADVT

where

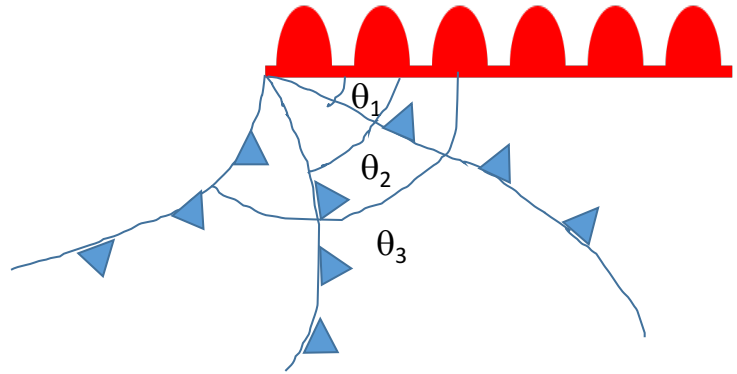
$$Q = \int_{ptop}^{psrf} q \frac{dp}{g}$$

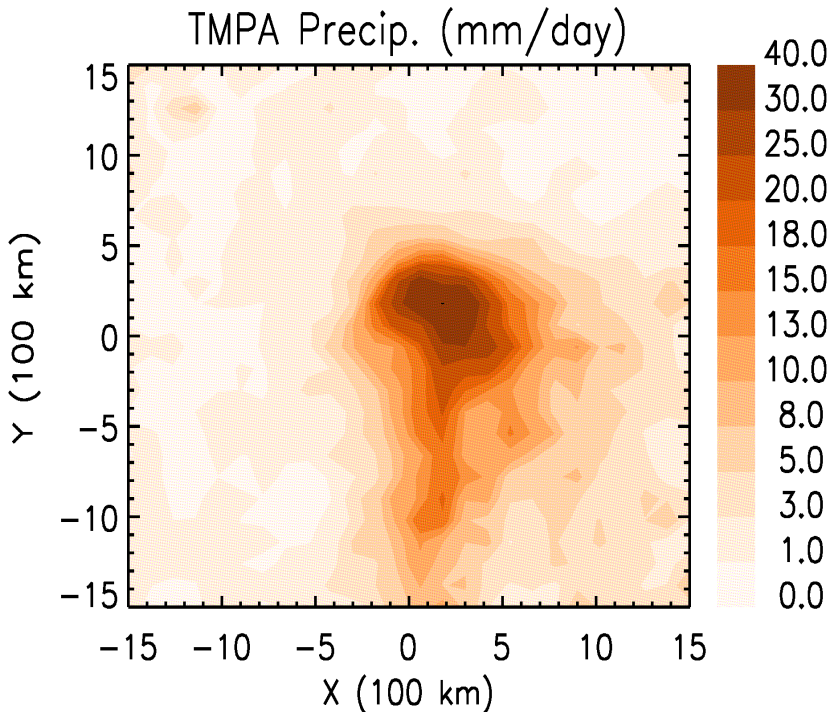
$$\vec{V} = \frac{1}{Q} \int_{ptop}^{psrf} (q\vec{v}) \frac{dp}{g}$$

P: Precipitation

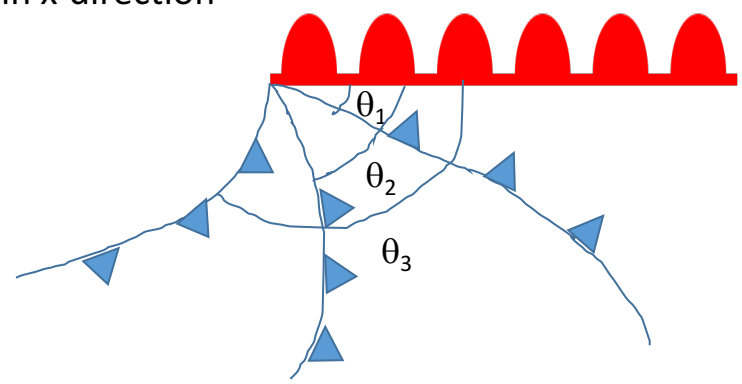
E: Evaporation

Warm-Front in x-direction

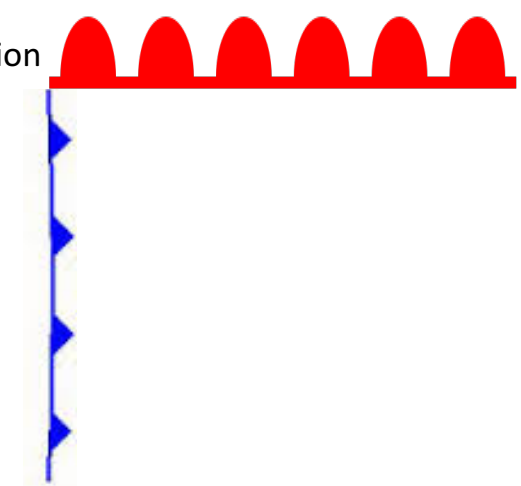


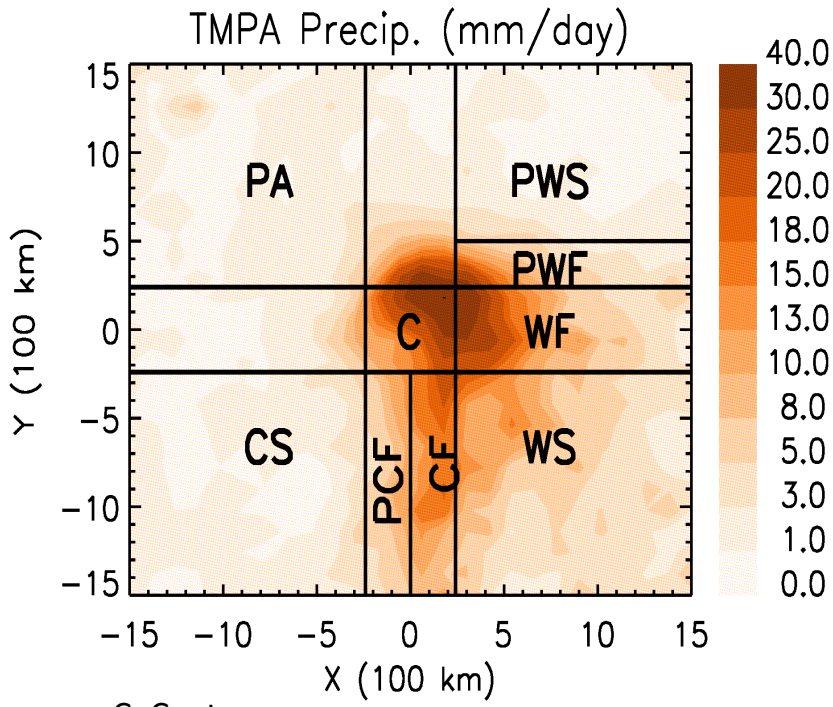


Warm-Front in x-direction



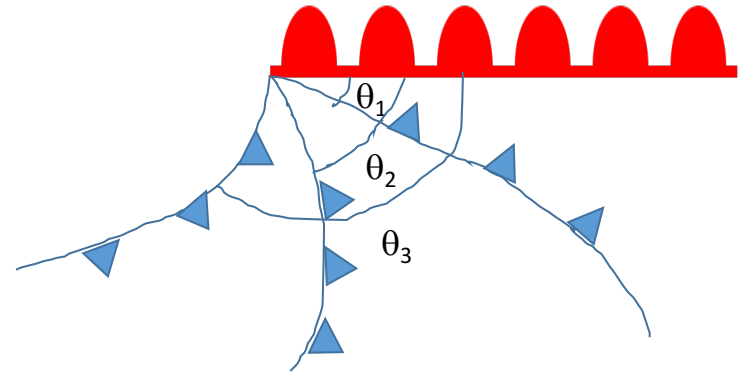
Warm-Front in x-direction
Cold-Fron in negative y-direction



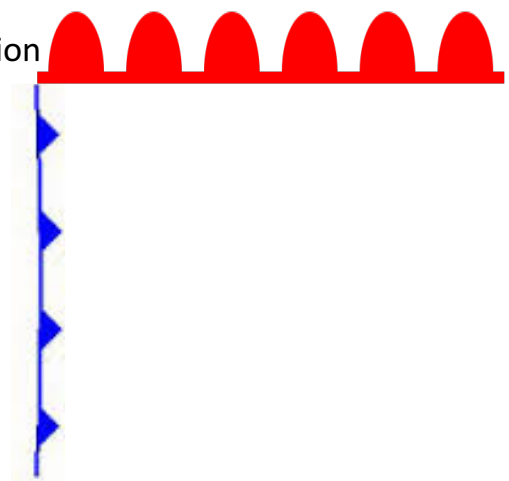


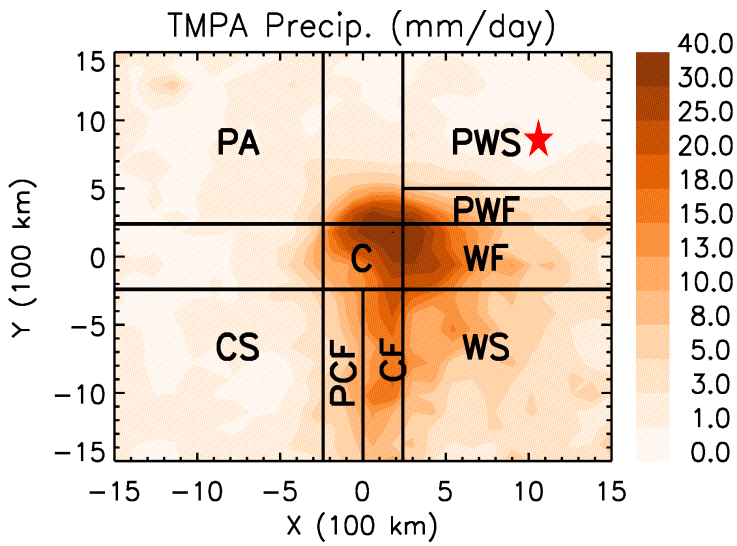
C: Center
PWS: Pre-Warm Sector
PWF: Pre-Warm Front
WF: Warm Front
WS: Warm Sector
CF: Cold Front
PCF: Post-Cold Front
CS: Cold Sector
PA: Polar Air Intrusion

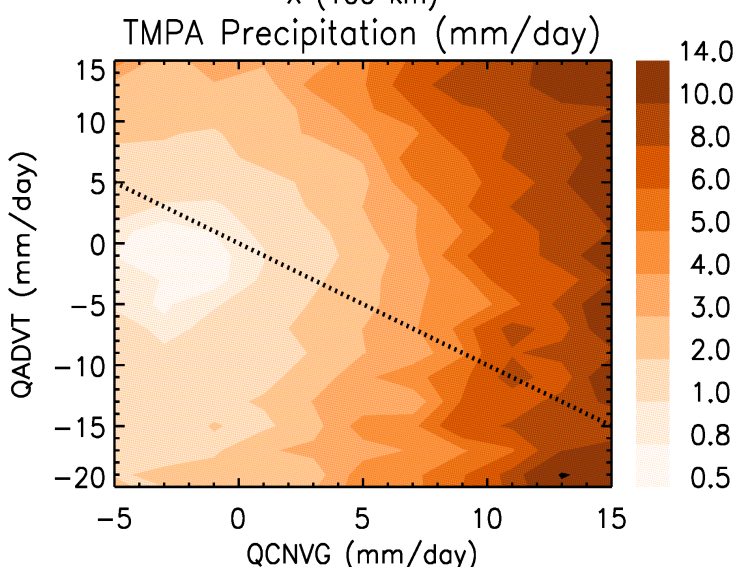
Warm-Front in x-direction



Warm-Front in x-direction
Cold-Front in negative y-direction



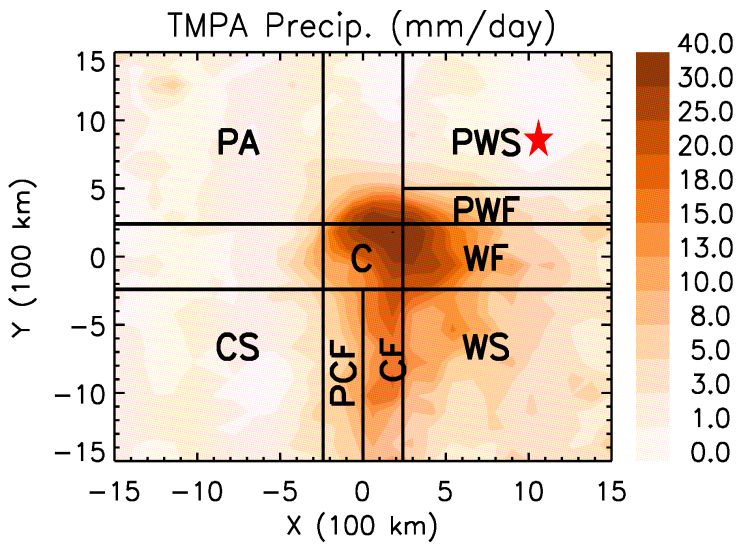




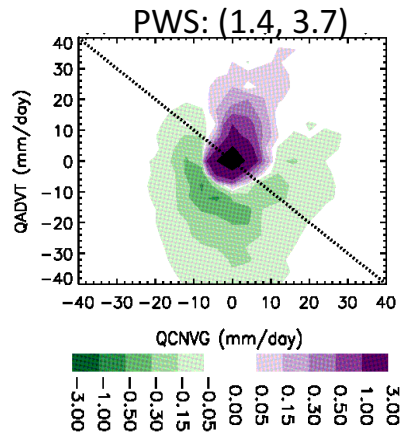
Qcnvg-Qadvt

MODIS CTP-COD

ω Profiles

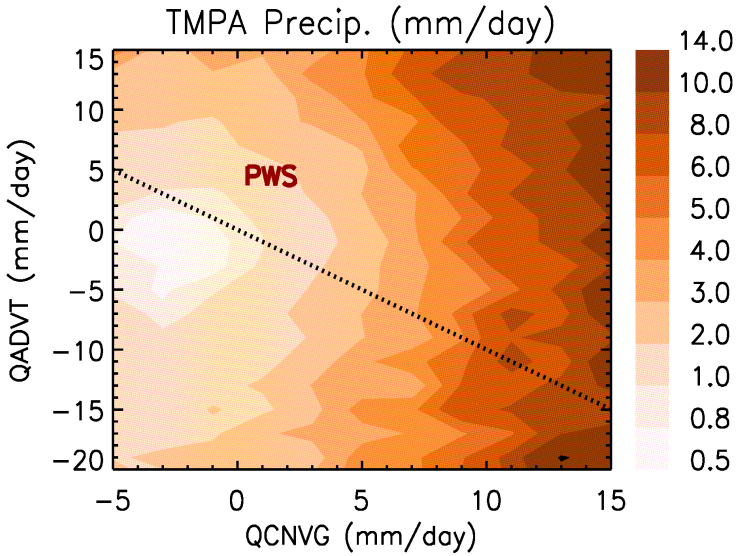


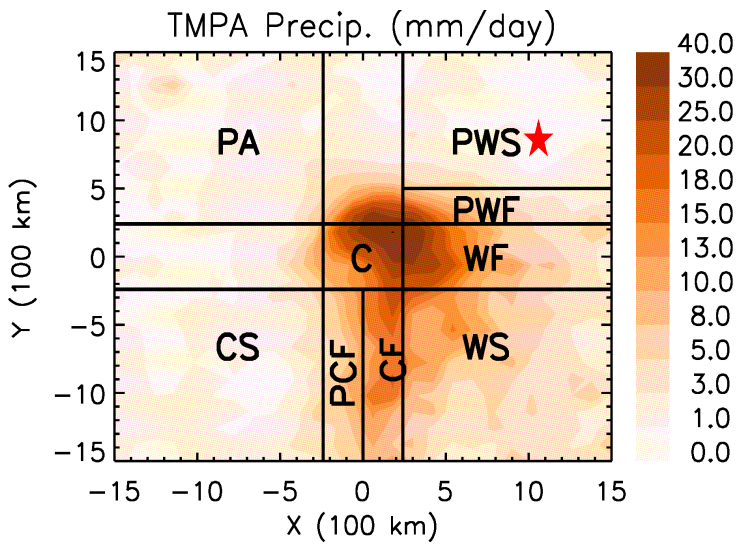
Qcnvg-Qadvt

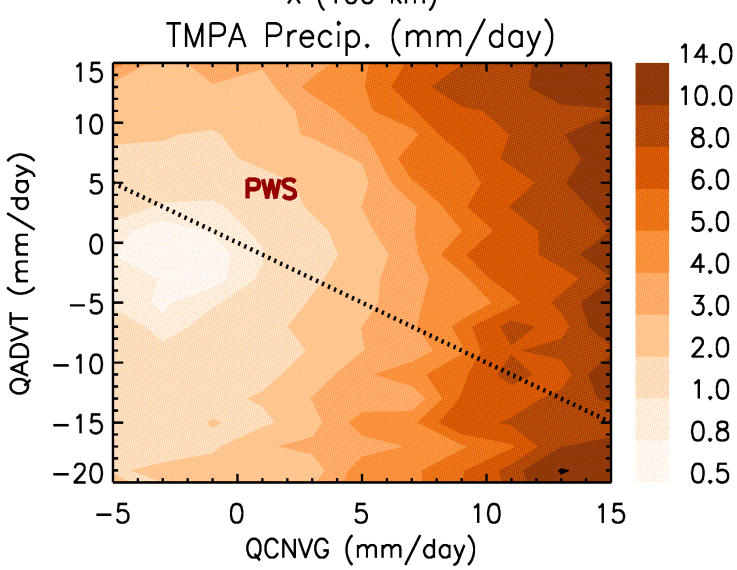


MODIS CTP-COD

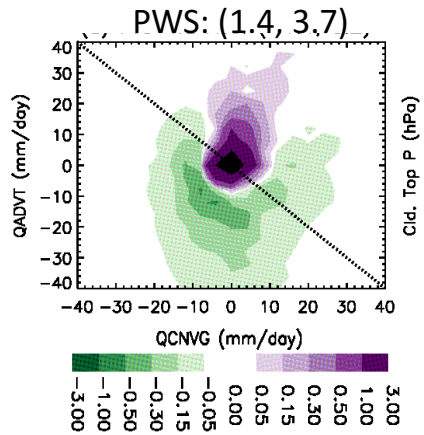
ω Profiles



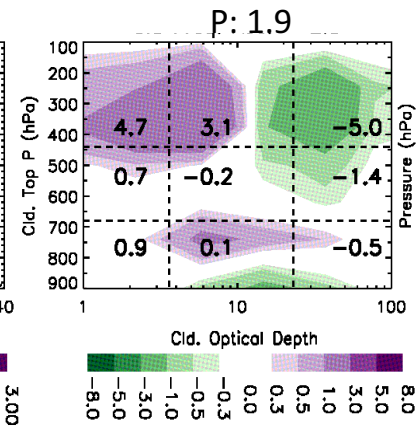




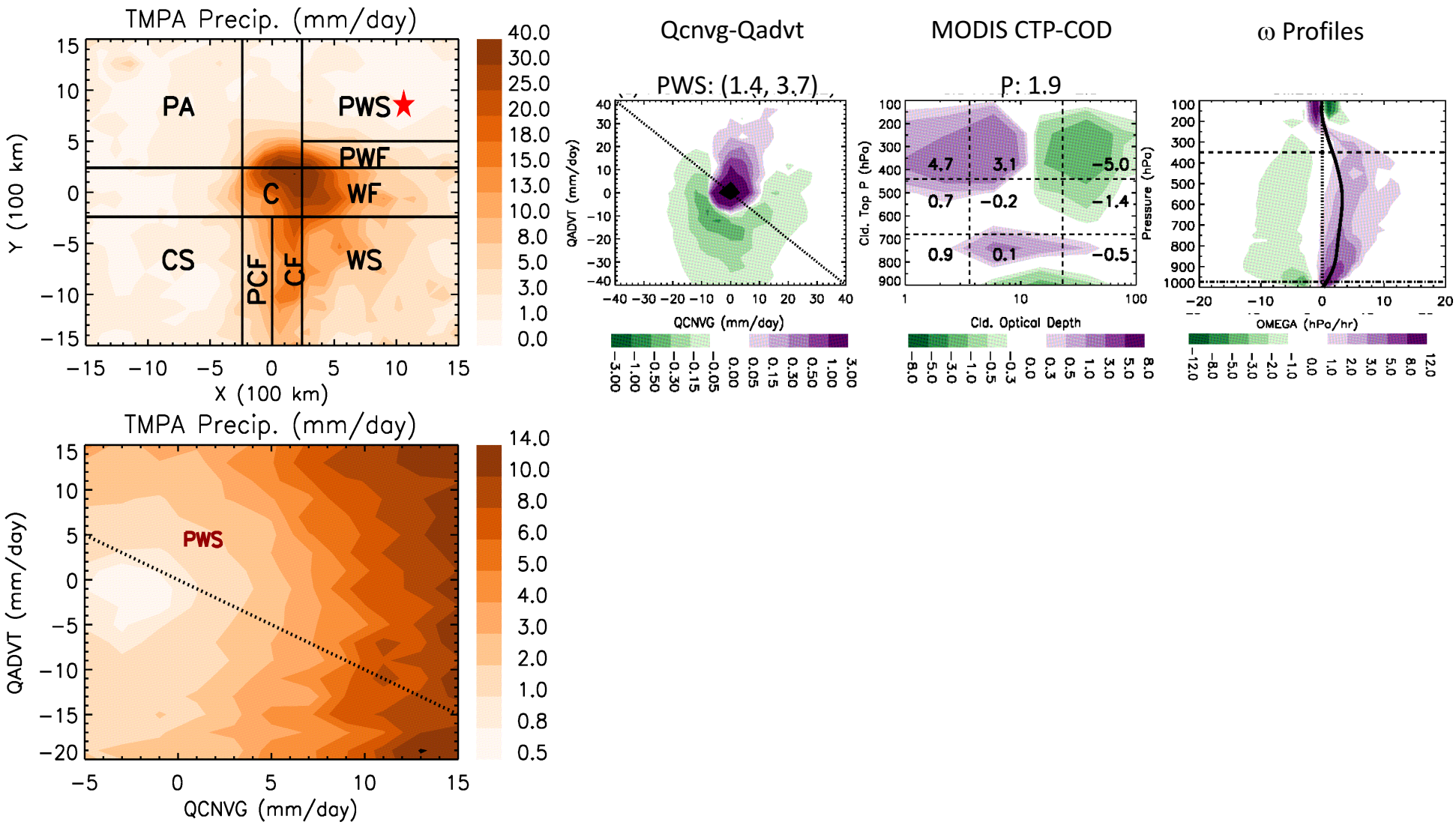
Qcnvg-Qadvt

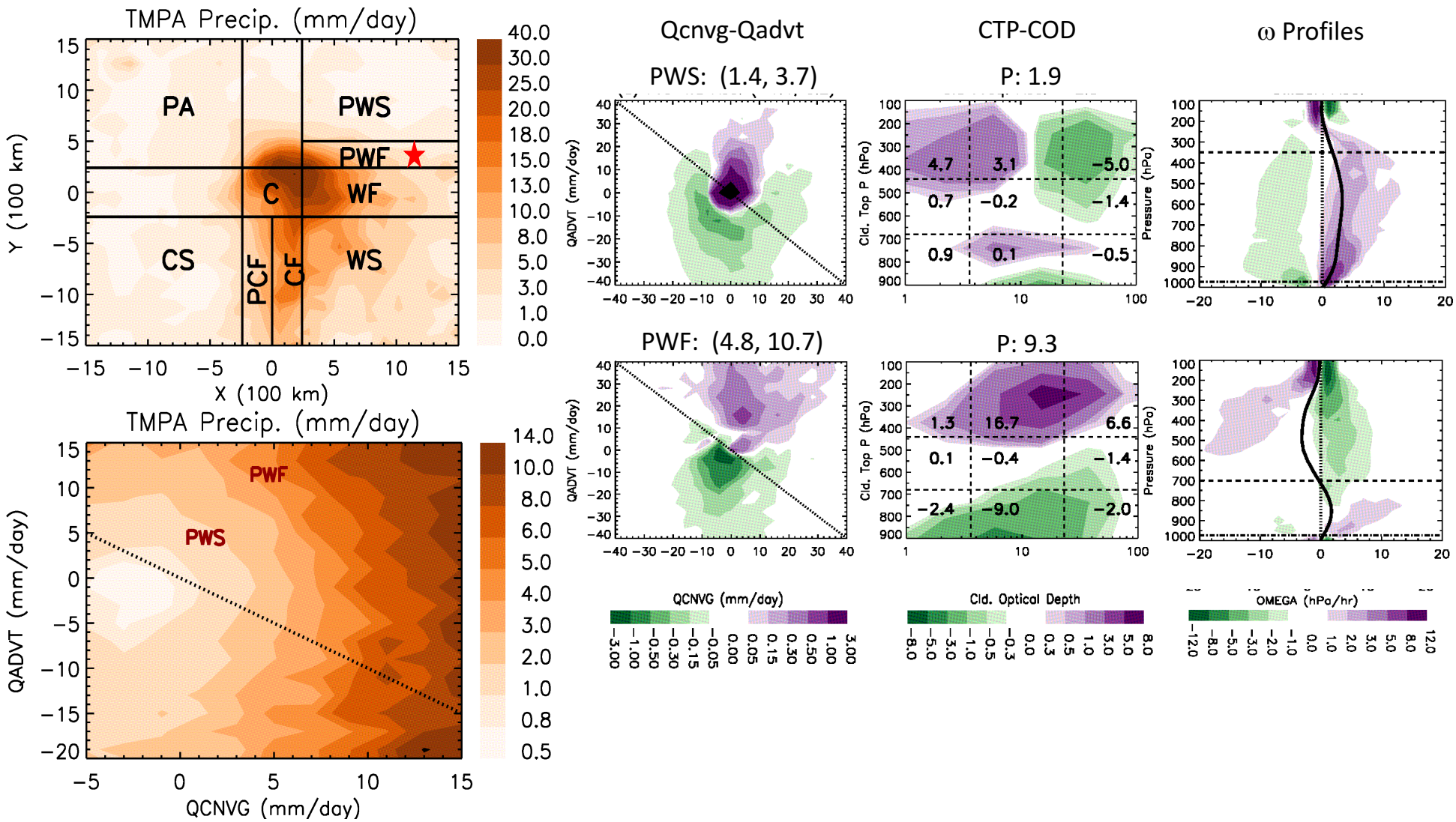


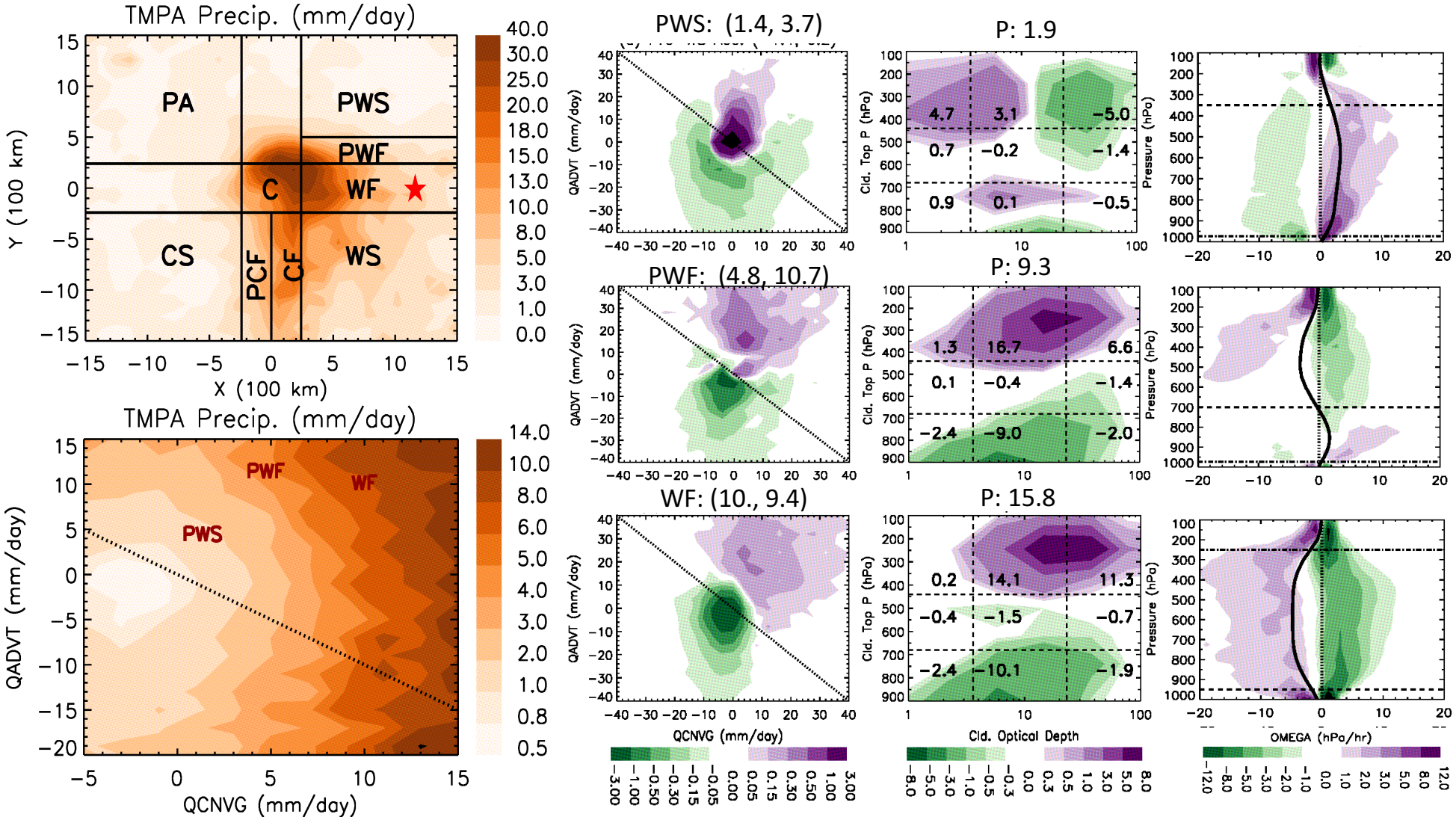
MODIS CTP-COD

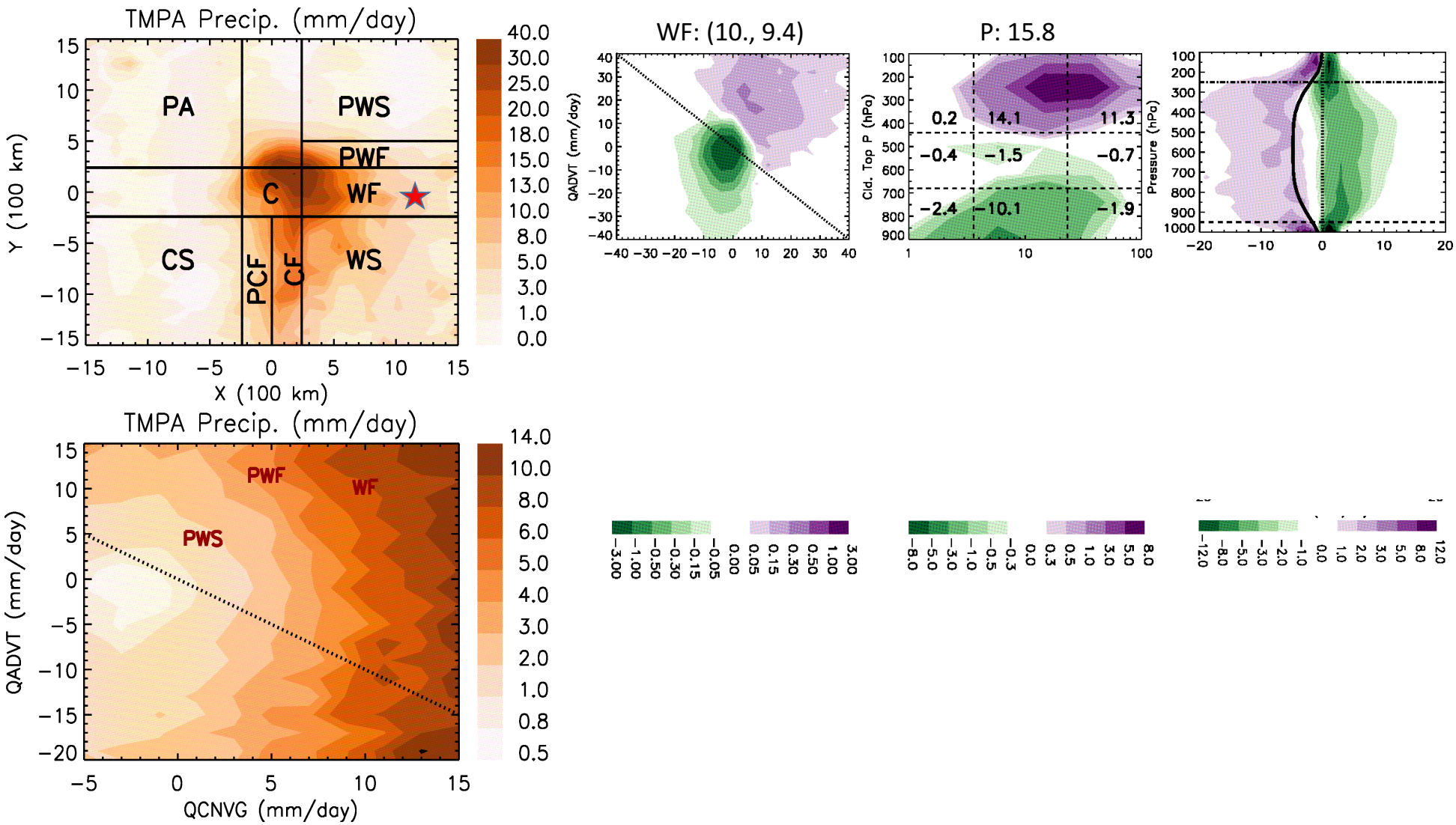


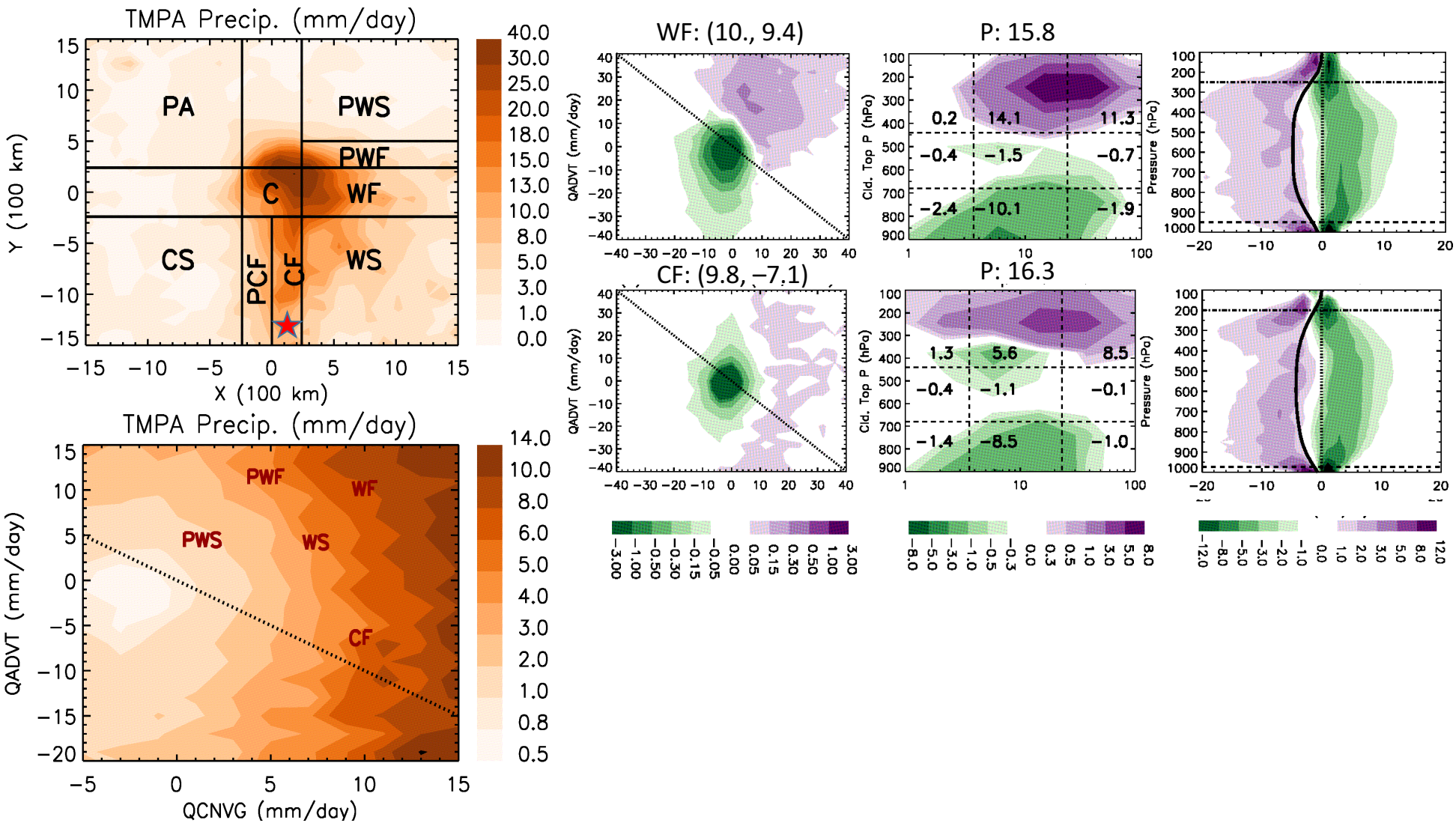
ω Profiles

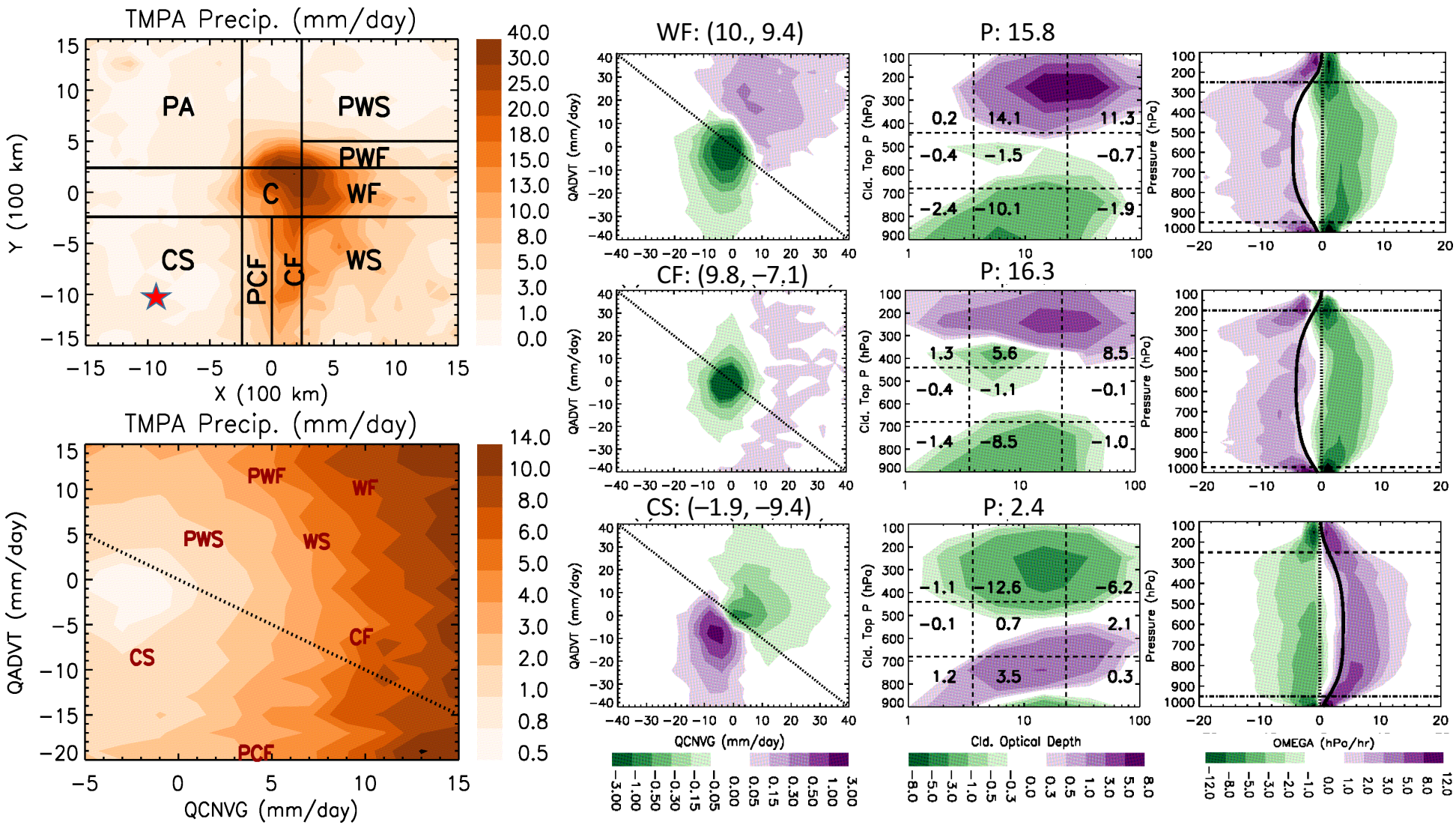

TMPA Precip. (mm/day)
PA
PWS
PWF
C
WF
CS
PCF
CF
WS
Y (100 km)
X (100 km)
Qcnvg-Qadvt
PWS: (1.4, 3.7)
QADVT (mm/day)
QCNVG (mm/day)
MODIS CTP-COD
P: 1.9
Cld. Top P (hPa)
Pressure (hPa)
Cld. Optical Depth
ω Profiles
OMEGA (hPa/hr)
TMPA Precip. (mm/day)
PWS
QADVT (mm/day)
QCNVG (mm/day)


TMPA Precip. (mm/day)
PA
PWS
PWF
C
WF
CS
PCF
CF
WS
Y (100 km)
X (100 km)
TMPA Precip. (mm/day)
PWF
PWS
QADVT (mm/day)
QCNVG (mm/day)
Qcnvg-Qadvt
PWS: (1.4, 3.7)
PWF: (4.8, 10.7)
CTP-COD
P: 1.9
P: 9.3
Cld. Top P (hPa)
Pressure (hPa)
4.7
3.1
−5.0
0.7
−0.2
−1.4
0.9
0.1
−0.5
1.3
16.7
6.6
0.1
−0.4
−1.4
−2.4
−9.0
−2.0
ω Profiles
QCNVG (mm/day)
Cld. Optical Depth
OMEGA (hPa/hr)

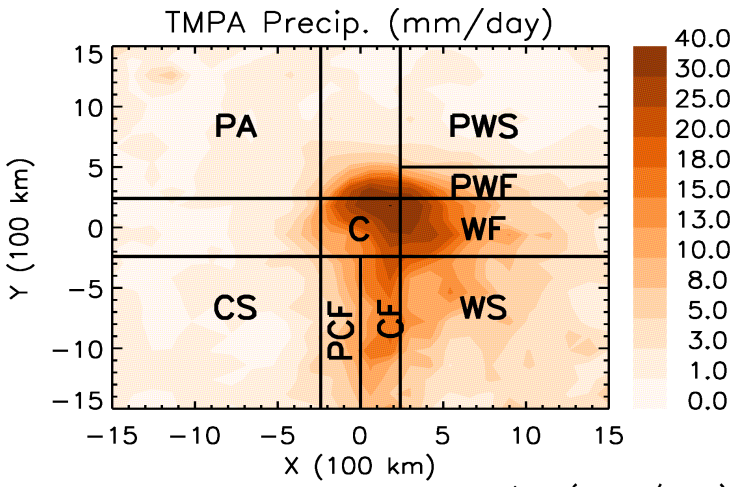

TMPA Precip. (mm/day)
PA
PWS
PWF
C
WF
CS
PCF
CF
WS
Y (100 km)
X (100 km)
TMPA Precip. (mm/day)
PWF
WF
PWS
QADVT (mm/day)
QCNVG (mm/day)
PWS: (1.4, 3.7)
P: 1.9
PWF: (4.8, 10.7)
P: 9.3
WF: (10., 9.4)
P: 15.8
QADVT (mm/day)
Cld. Top P (hPa)
Pressure (hPa)
QCNVG (mm/day)
Cld. Optical Depth
OMEGA (hPa/hr)

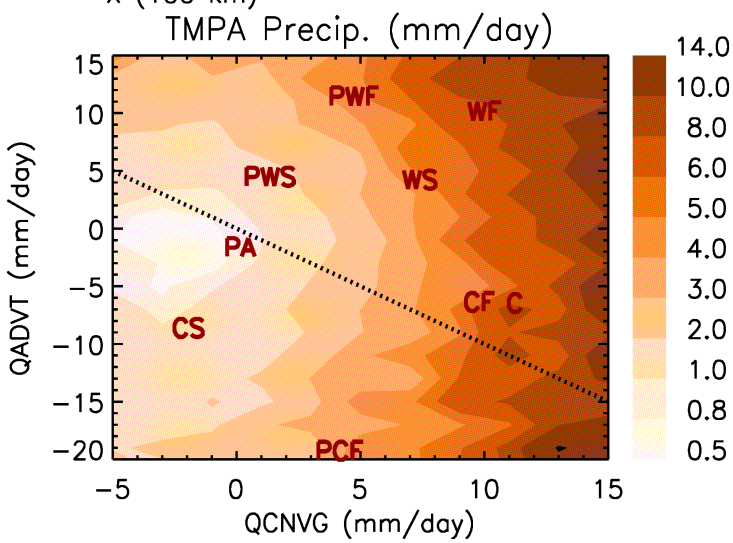

TMPA Precip. (mm/day)
PA
PWS
PWF
C
WF
CS
PCF
CF
WS
Y (100 km)
X (100 km)
WF: (10., 9.4)
QADVT (mm/day)
P: 15.8
Cld. Top P (hPa)
0.2
14.1
11.3
−0.4
−1.5
−0.7
−2.4
−10.1
−1.9
Pressure (hPa)
TMPA Precip. (mm/day)
PWF
WF
PWS
QADVT (mm/day)
QCNVG (mm/day)

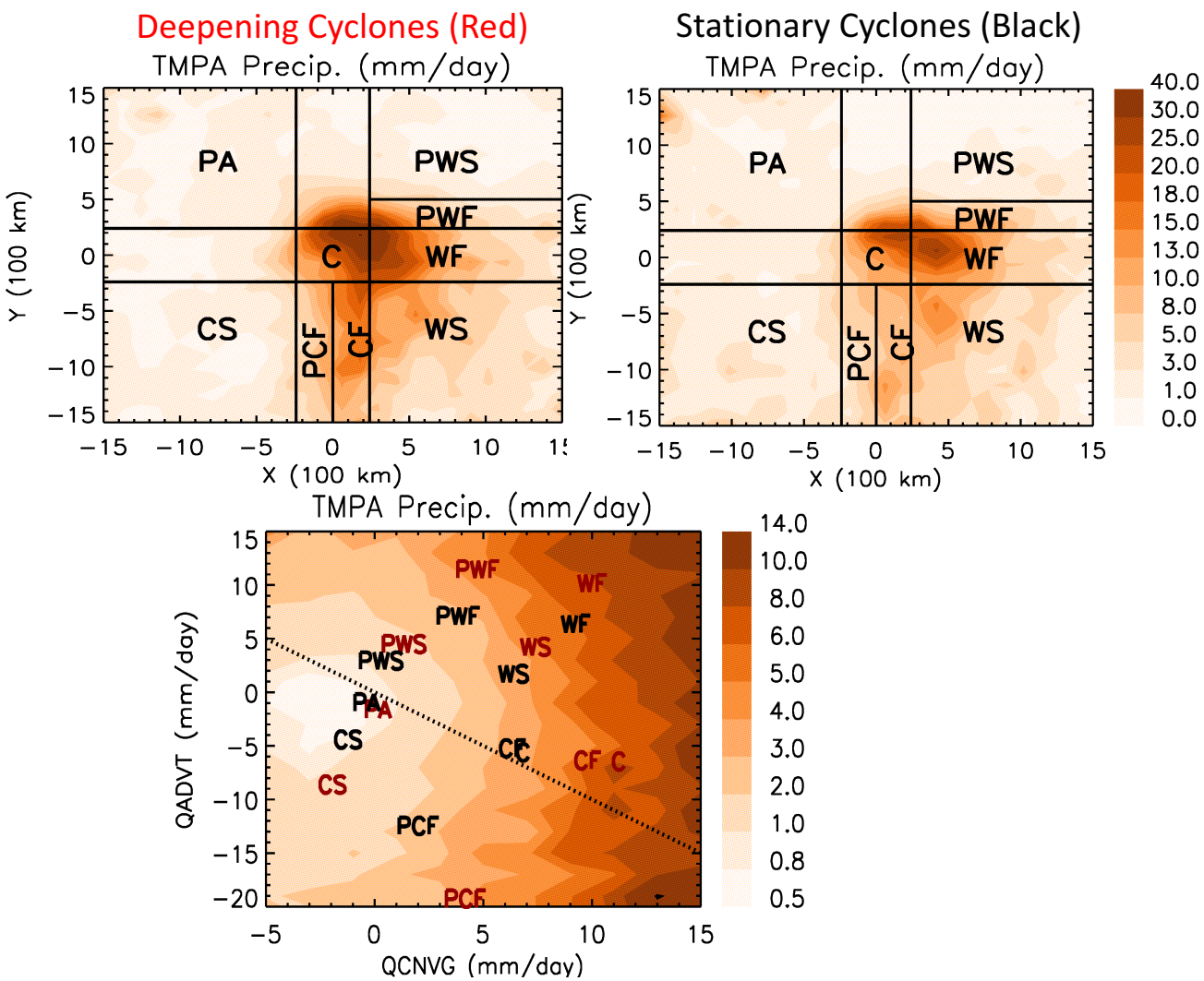

TMPA Precip. (mm/day)
PA
PWS
PWF
C
WF
CS
PCF
CF
WS
Y (100 km)
X (100 km)
TMPA Precip. (mm/day)
PWF
WF
PWS
WS
CF
QADVT (mm/day)
QCNVG (mm/day)
WF: (10., 9.4)
P: 15.8
CF: (9.8, −7.1)
P: 16.3
QADVT (mm/day)
Cld. Top P (hPa)
Pressure (hPa)
0.2
14.1
11.3
−0.4
−1.5
−0.7
−2.4
−10.1
−1.9
1.3
5.6
8.5
−0.4
−1.1
−0.1
−1.4
−8.5
−1.0

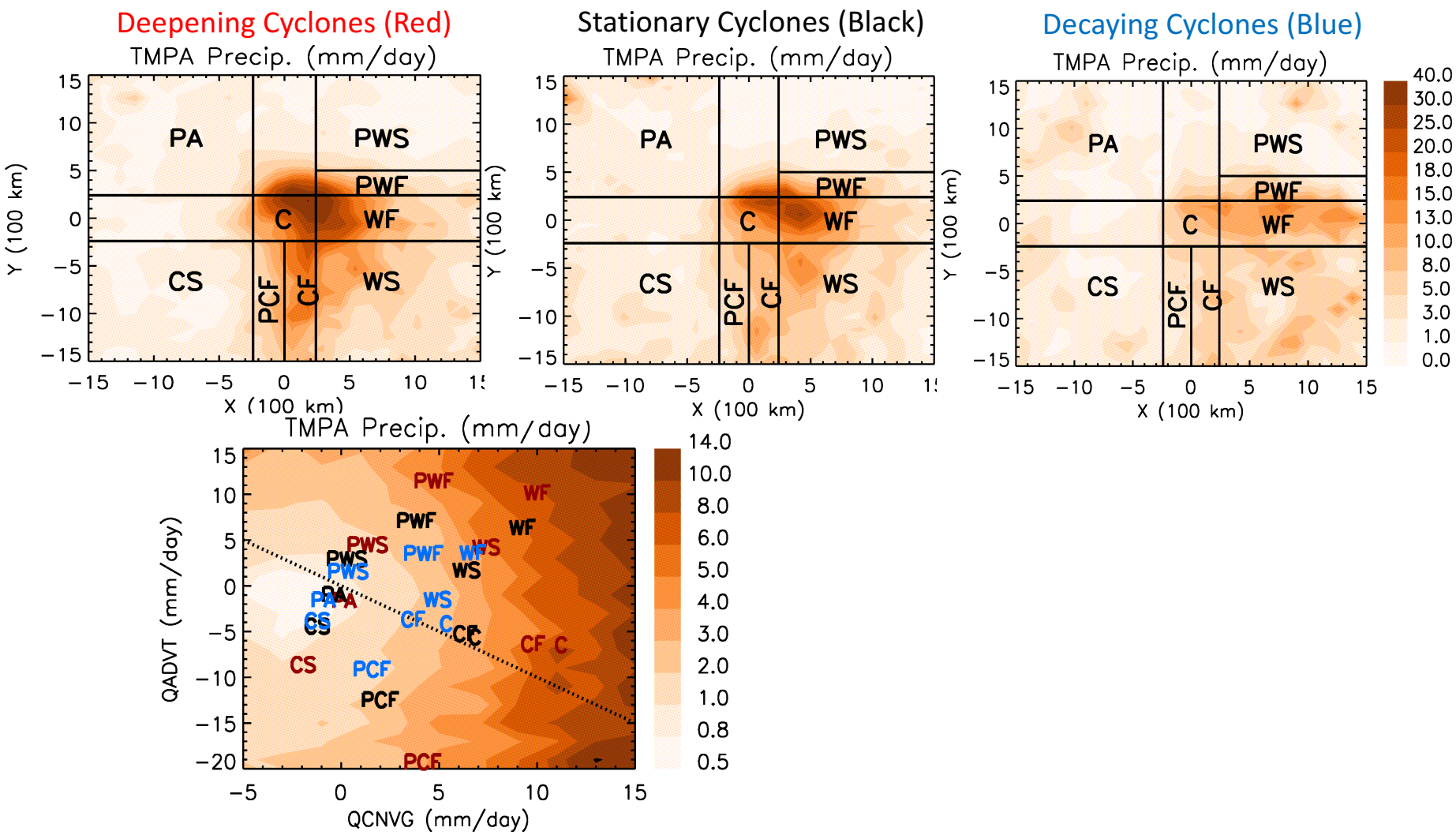

TMPA Precip. (mm/day)
PA
PWS
PWF
C
WF
CS
PCF
CF
WS
Y (100 km)
X (100 km)
TMPA Precip. (mm/day)
PWF
WF
PWS
WS
CS
CF
PCF
QADVT (mm/day)
QCNVG (mm/day)
WF: (10., 9.4)
P: 15.8
0.2
14.1
11.3
−0.4
−1.5
−0.7
−2.4
−10.1
−1.9
CF: (9.8, −7.1)
P: 16.3
1.3
5.6
8.5
−0.4
−1.1
−0.1
−1.4
−8.5
−1.0
CS: (−1.9, −9.4)
P: 2.4
−1.1
−12.6
−6.2
−0.1
0.7
2.1
1.2
3.5
0.3
QADVT (mm/day)
Cld. Top P (hPa)
Pressure (hPa)
QCNVG (mm/day)
Cld. Optical Depth
OMEGA (hPa/hr)

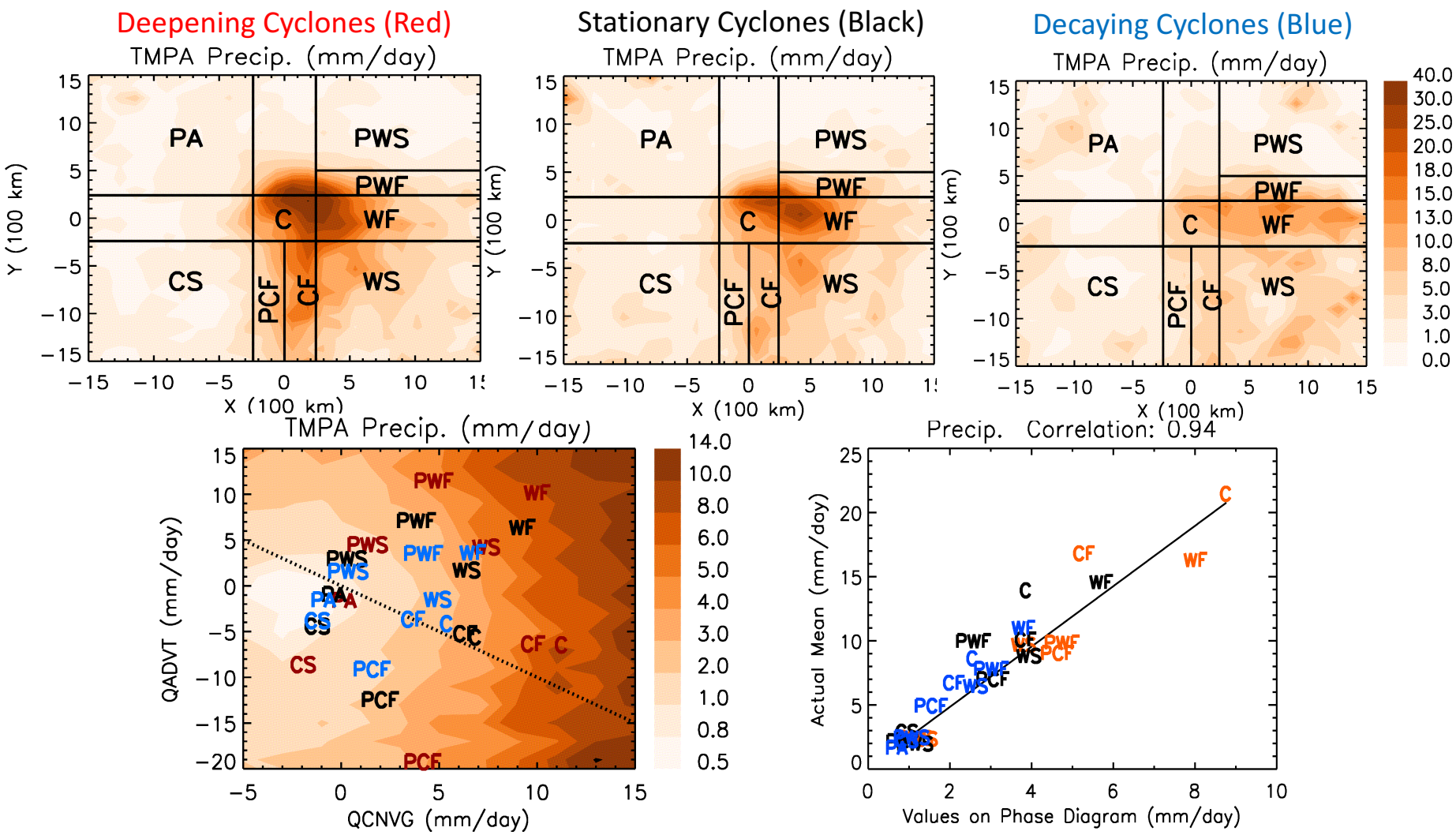
Deepening Cyclones (Red)






Deepening Cyclones (Red)
TMPA Precip. (mm/day)
PA
PWS
PWF
C
WF
CS
PCF
CF
WS
Y (100 km)
X (100 km)
Stationary Cyclones (Black)
TMPA Precip. (mm/day)
40.0
30.0
25.0
20.0
18.0
15.0
13.0
10.0
8.0
5.0
3.0
1.0
0.0
TMPA Precip. (mm/day)
QADVT (mm/day)
QCNVG (mm/day)
14.0
10.0
8.0
6.0
5.0
4.0
3.0
2.0
1.0
0.8
0.5


Deepening Cyclones (Red)
Stationary Cyclones (Black)
Decaying Cyclones (Blue)
TMPA Precip. (mm/day)
PA
PWS
PWF
C
WF
CS
PCF
CF
WS
Y (100 km)
X (100 km)
QADVT (mm/day)
QCNVG (mm/day)


Deepening Cyclones (Red)
Stationary Cyclones (Black)
Decaying Cyclones (Blue)
TMPA Precip. (mm/day)
PA
PWS
PWF
C
WF
CS
PCF
CF
WS
Y (100 km)
X (100 km)
QADVT (mm/day)
QCNVG (mm/day)
Precip. Correlation: 0.94
Actual Mean (mm/day)
Values on Phase Diagram (mm/day)

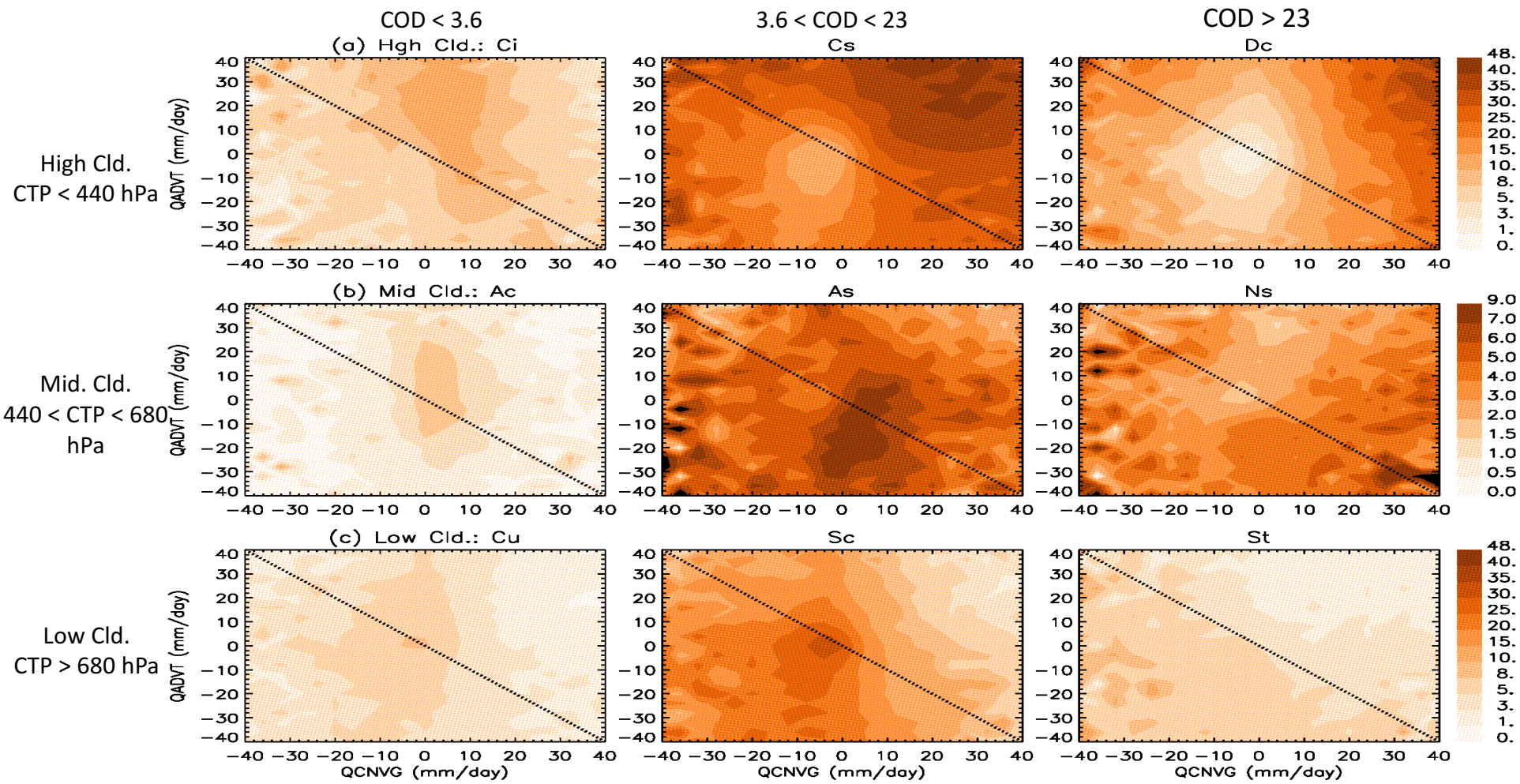
Conclusions:

- Ways of moisture transport ($-Q\nabla\cdot\mathbf{V}$ vs $-\mathbf{V}\cdot\nabla Q$) control precipitation variability and cloud organization in ETCs.

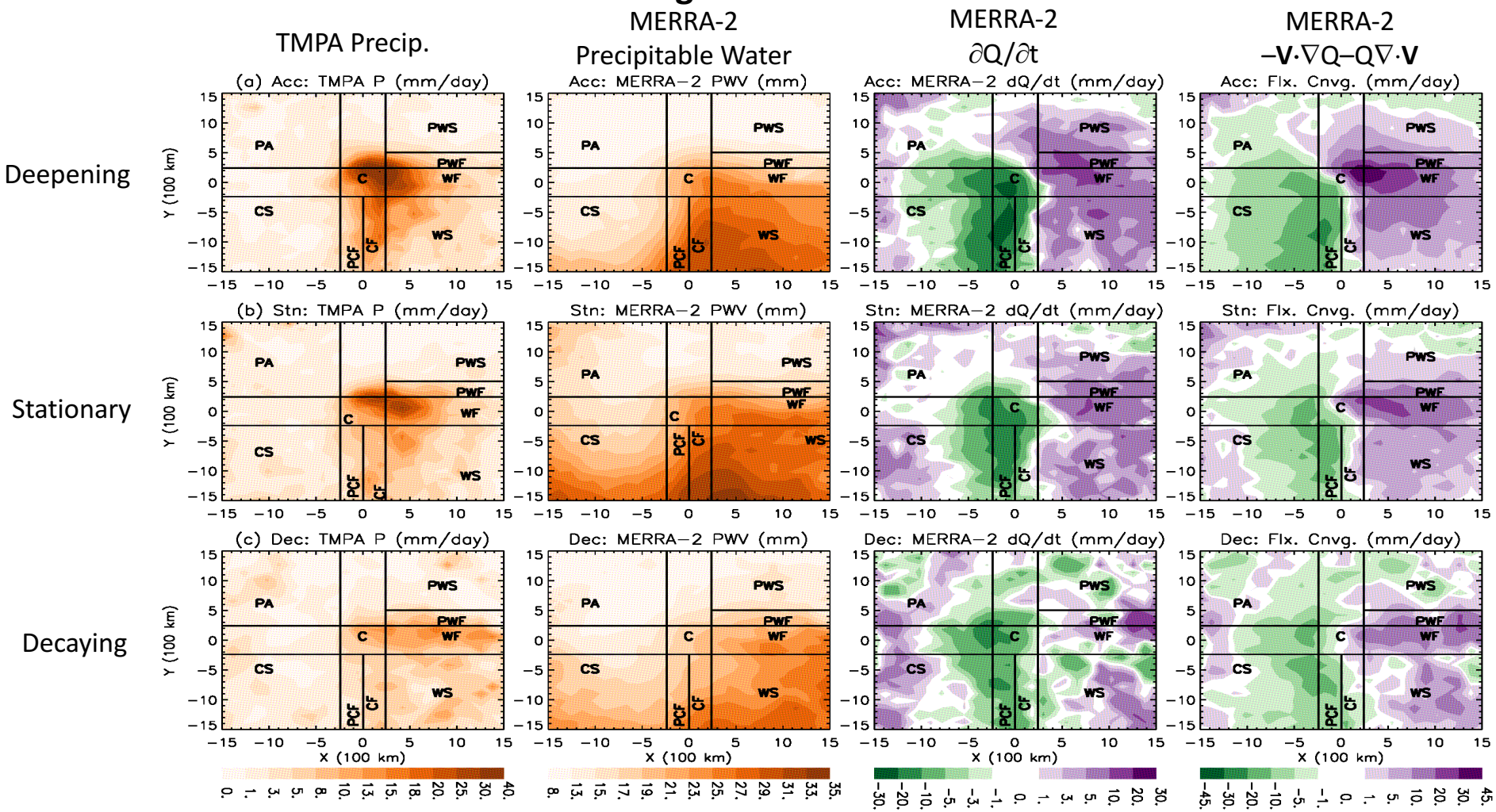
- Deepening ETCs have rapid moisture supply and ventilation by the atmosphere, while decaying ETCs correspond to slower moisture transport processes.

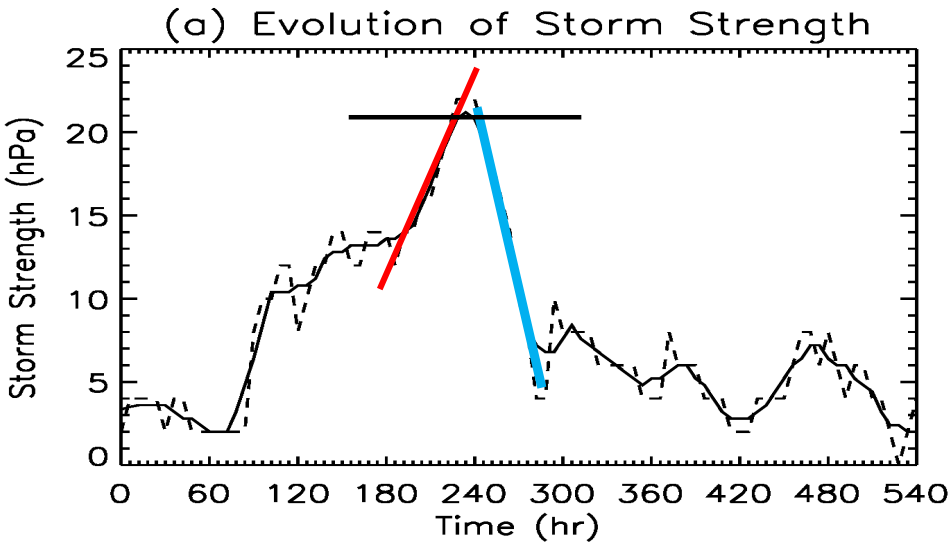
- Deepening ETCs are the most efficient in meridional transport of water vapor.

Cloud Organization in ETCs



Moisture Budget Around ETC Centers



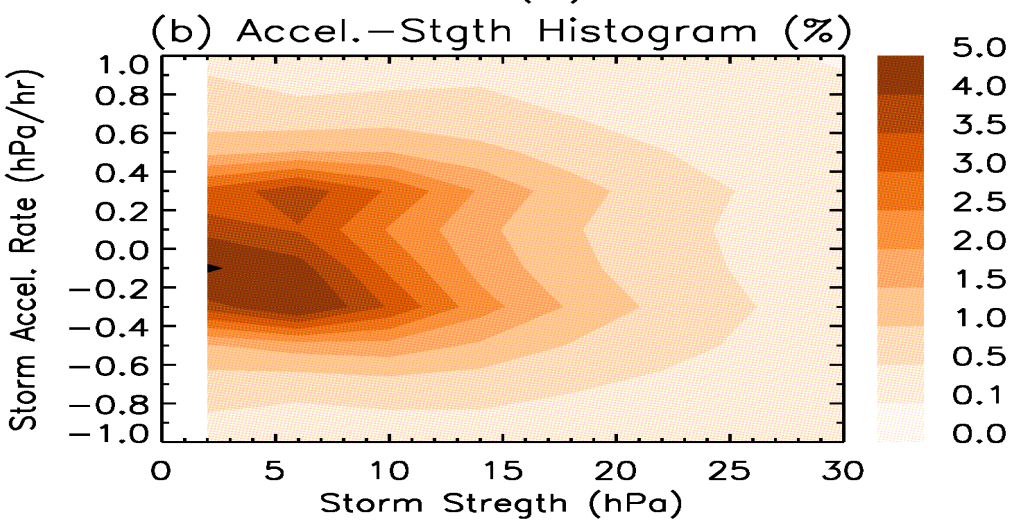


Definition of Cyclone Development Stages

Deepening cyclones

Stationary cyclones

Decaying cyclones



Joint Histogram of Cyclone Center Depth Acceleration (dD/dt) and Center Depth (Strength)