Aerosols and Tropical Cyclone Formation

Chris Collimore

NOAA-CREST

Hurricanes

Tropical Storms

Tropical Depressions

} Tropical Cyclones

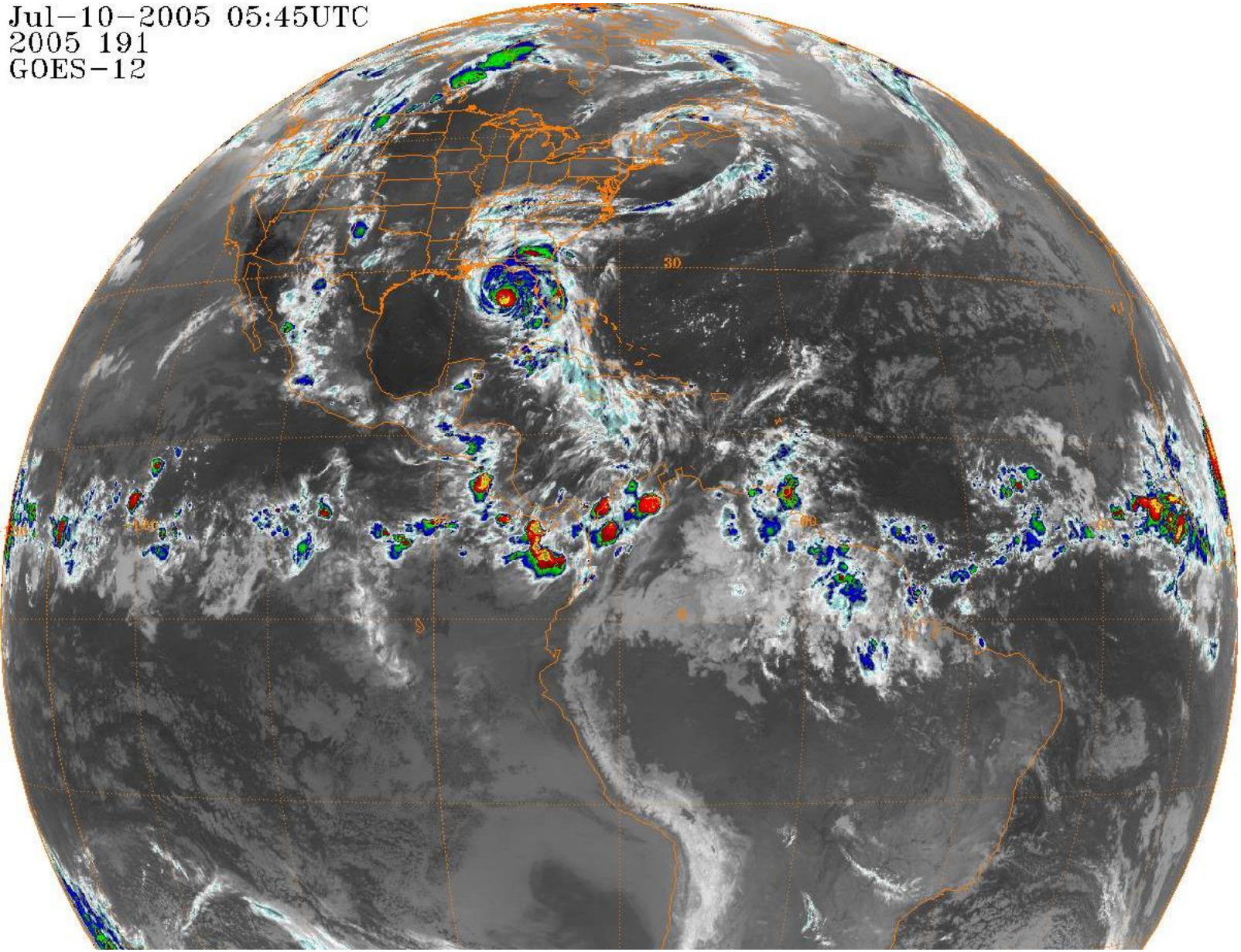
Hurricanes

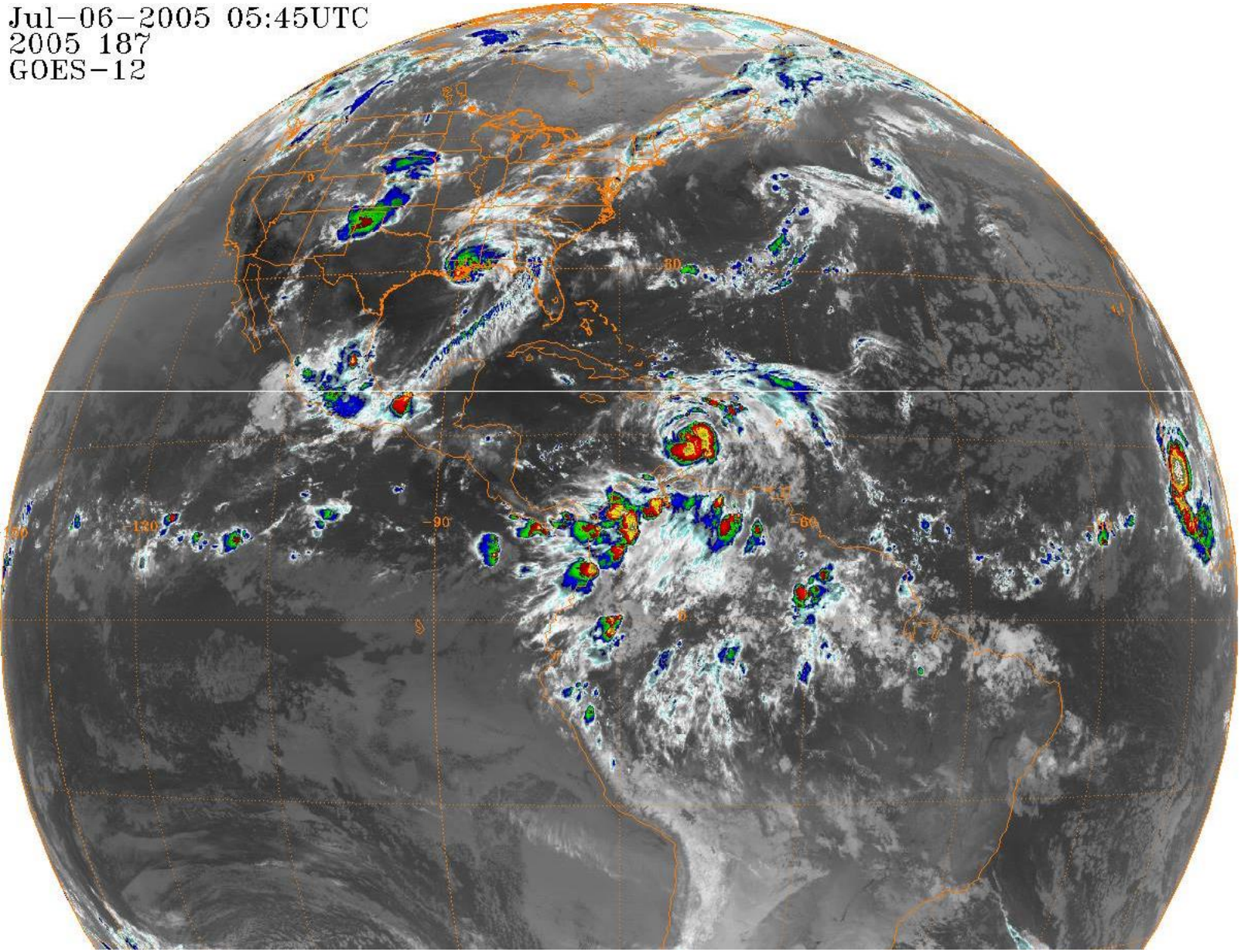
Tropical Storms

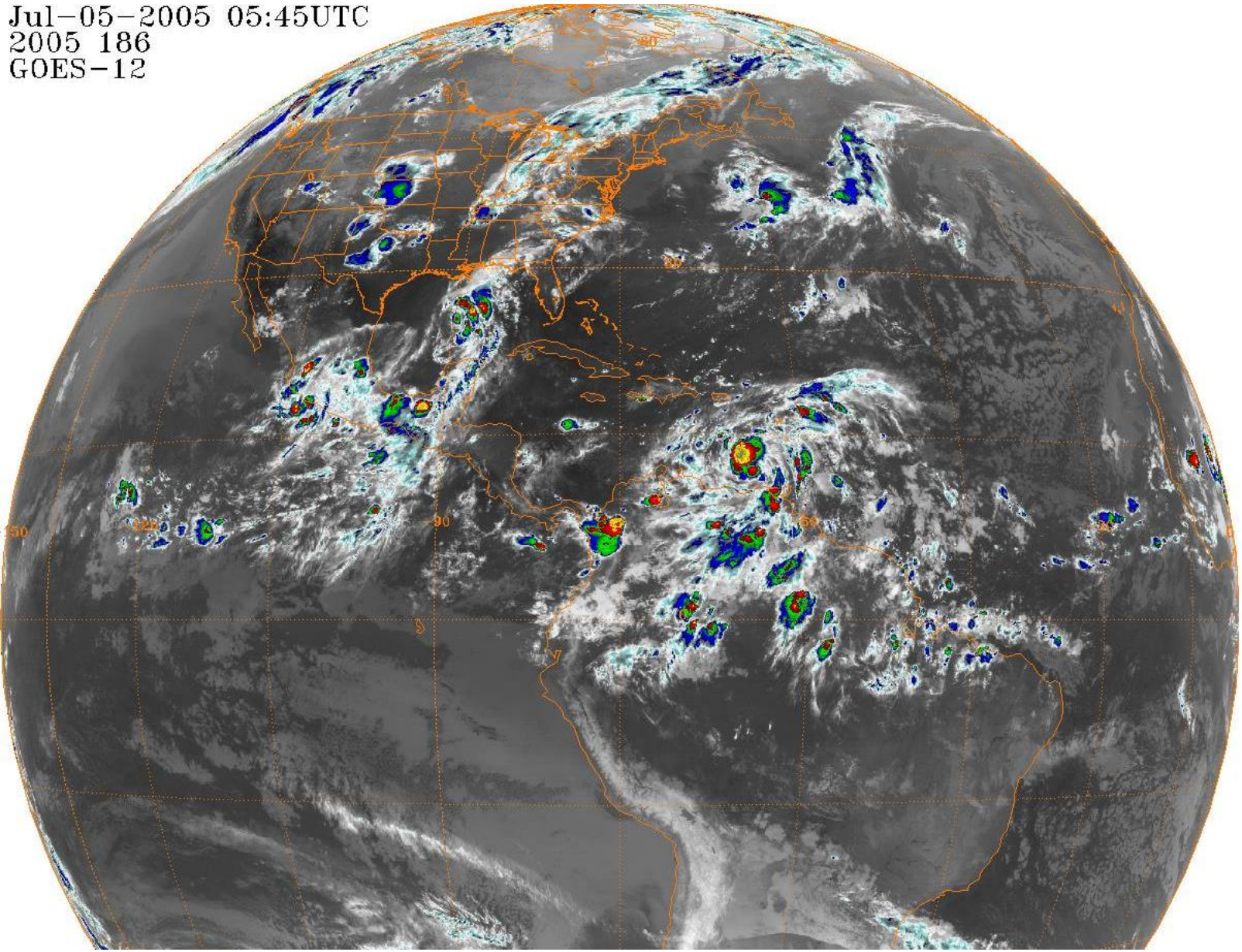
Tropical Depressions

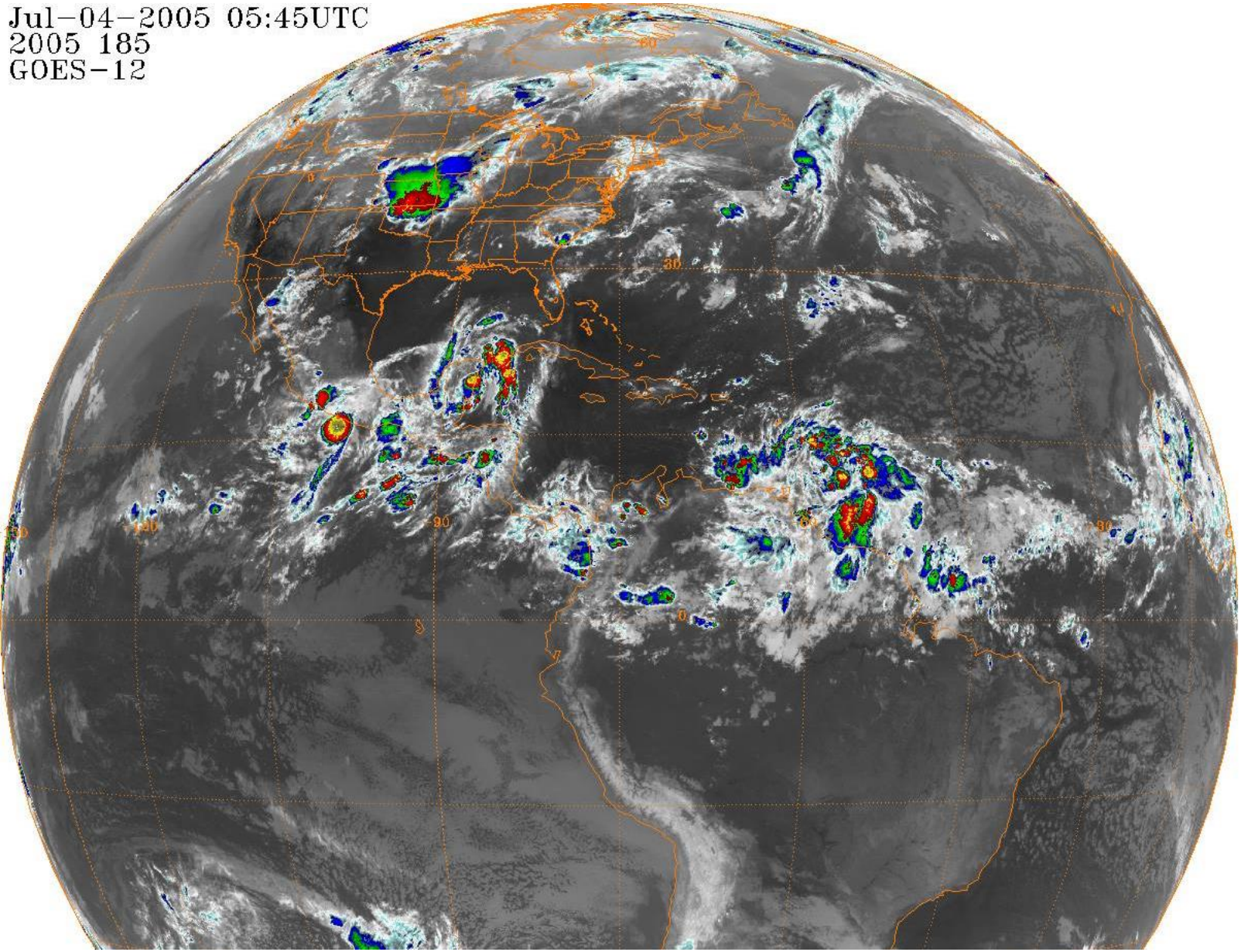
} Tropical Cyclones

Background on TC formation


Jul-10-2005 05:45UTC
2005 191
GOES-12


Jul-06-2005 05:45UTC
2005 187
GOES-12


Jul-05-2005 05:45UTC
2005 186
GOES-12


Jul-04-2005 05:45UTC
2005 185
GOES-12

TCs start as much smaller cloud clusters

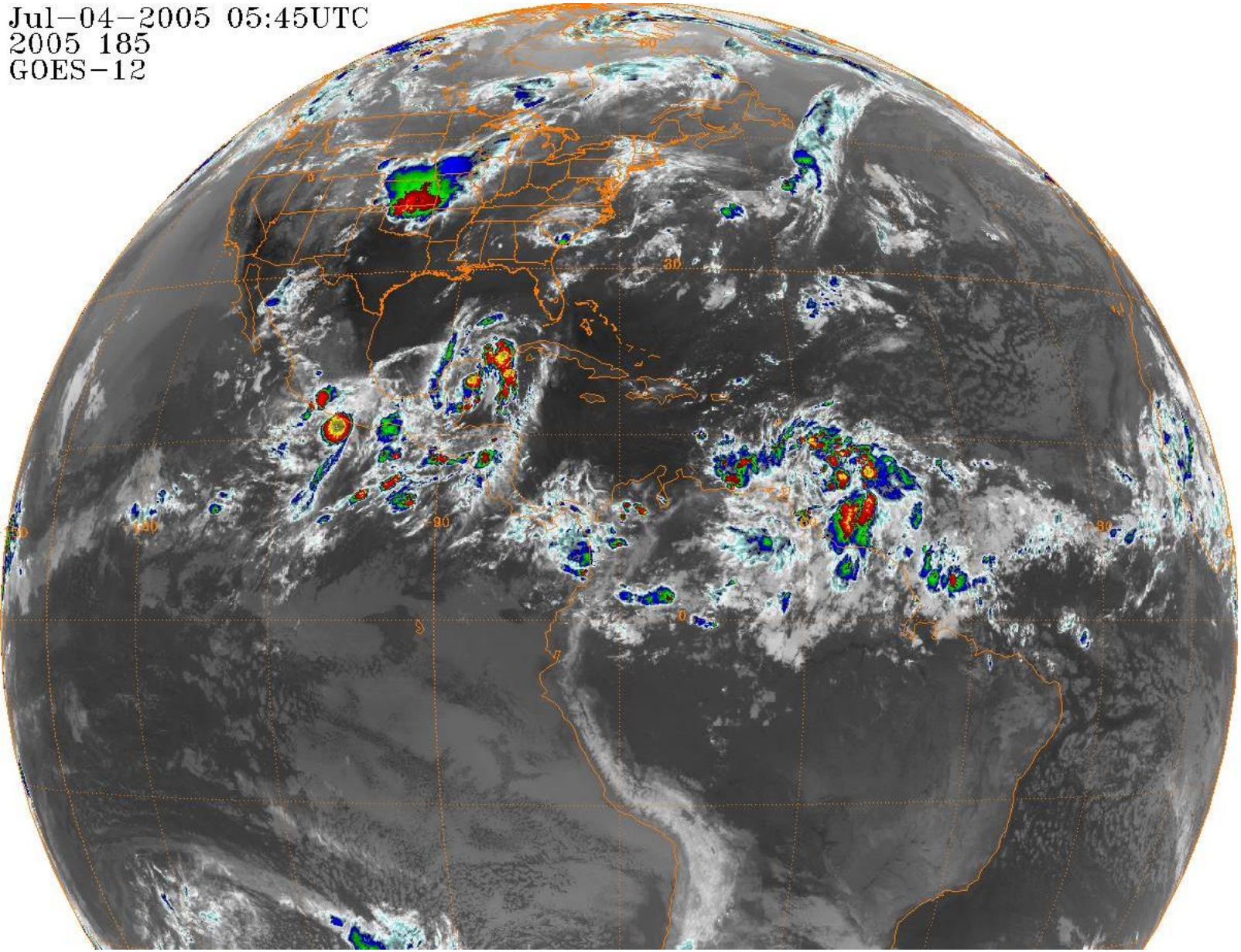
(consisting of primarily convective clouds)

The National Hurricane Center monitors the location (and other parameters) of cloud clusters that show promise of developing into TCs.

Prediction of TC formation needs improvement: cloud clusters often dissipate for reasons unknown.

This is problematic because TCs can form in a matter of hours.

How do forecasters predict formation?


Jul-04-2005 05:45UTC
2005 185
GOES-12

THE "BIG FIVE" ENVIRONMENTAL FACTORS IMPORTANT FOR TC FORMATION

1. Warm sea surface temperature (26.5° C)
2. High mid-level humidity
3. Conditionally unstable (neutral?) lapse rates
4. Weak vertical wind shear
5. High low-level vorticity

THE "BIG FIVE" ENVIRONMENTAL FACTORS IMPORTANT FOR TC FORMATION

1. Warm sea surface temperature (26.5° C)
2. High mid-level humidity
3. Conditionally unstable (neutral?) lapse rates
4. Weak vertical wind shear
5. High low-level vorticity

*Key for convection

What about **aerosols** in a cluster's environment?

More Aerosols – Stronger Convection

More aerosols (CCNs) → More, smaller, lighter droplets → Taller clouds →

Colder cloud tops: more freezing → More latent heat release aloft → Stronger updrafts/convection

Krall and Cotton, *Atmos. Chem. Phys. Discuss,* 2012

Many other studies have found similar results with models and observations

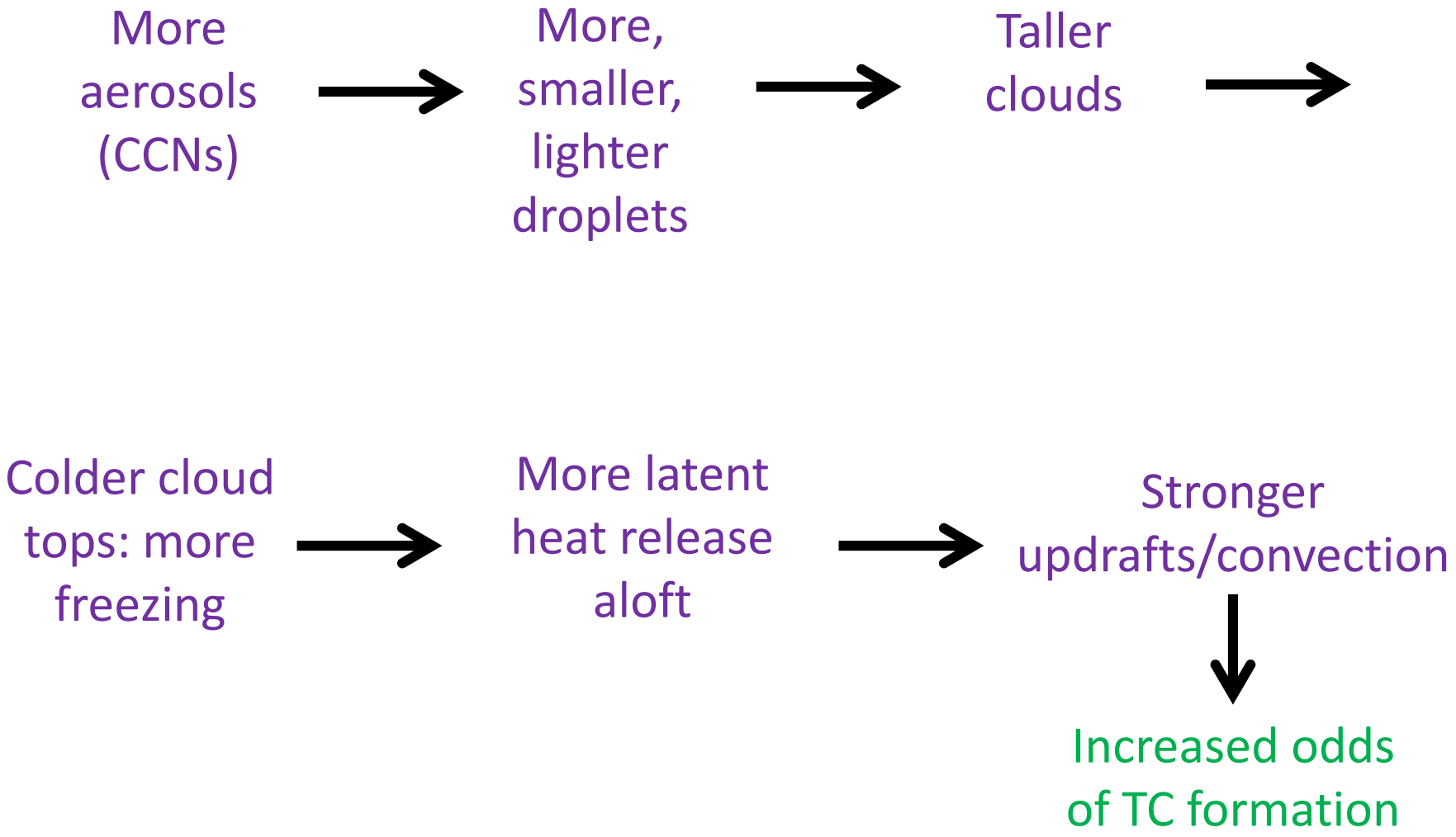
More aerosols – stronger convection

More aerosols (CCNs) → More, smaller, lighter droplets → Taller clouds →

Colder cloud tops: more freezing → More latent heat release aloft → Stronger updrafts/convection

Krall and Cotton, *Atmos. Chem. Phys. Discuss,* 2012

More aerosols near cluster – Greater likelihood of TC formation?



THE "BIG SIX?" ENVIRONMENTAL FACTORS IMPORTANT FOR TC FORMATION

1. Warm sea surface temperature (26.5° C)
2. High mid-level humidity
3. Conditionally unstable (neutral?) lapse rates
4. Weak vertical wind shear
5. High low-level vorticity
6. **High aerosol levels?**

Do high aerosol concentrations aid in TC formation?

To test this: aerosol amounts in the environment surrounding cloud clusters that developed into TCs (developers) were compared to aerosol amounts surrounding clusters that fizzled out (nondevelopers).

The process was repeated for other relevant parameters in the convective invigoration process (cloud droplet size, cloud top pressure,….)

Do high aerosol concentrations aid in TC formation?

If these parameters show more prominently in the developers, that is evidence that the invigoration process takes place more so in the developers than in the nondevelopers.

DATA

Cloud Clusters

- Cloud clusters in the Atlantic between 2005 and 2008 that were monitored by the National Hurricane Center
- 161 clusters
  - 63 developers
  - 98 nondevelopers

DATA

Cloud Clusters

- All developers were pre-genesis. No data was collected at genesis or afterward.

DATA

Aerosol Concentration

- Aerosol optical depth (**AOD**) from MODIS (Moderate Resolution Imaging Spectroradiometer) on the Terra Satellite.

- AOD is primarily a measure of how many aerosols are present in a column extending throughout the atmosphere (most aerosols will be in troposphere).

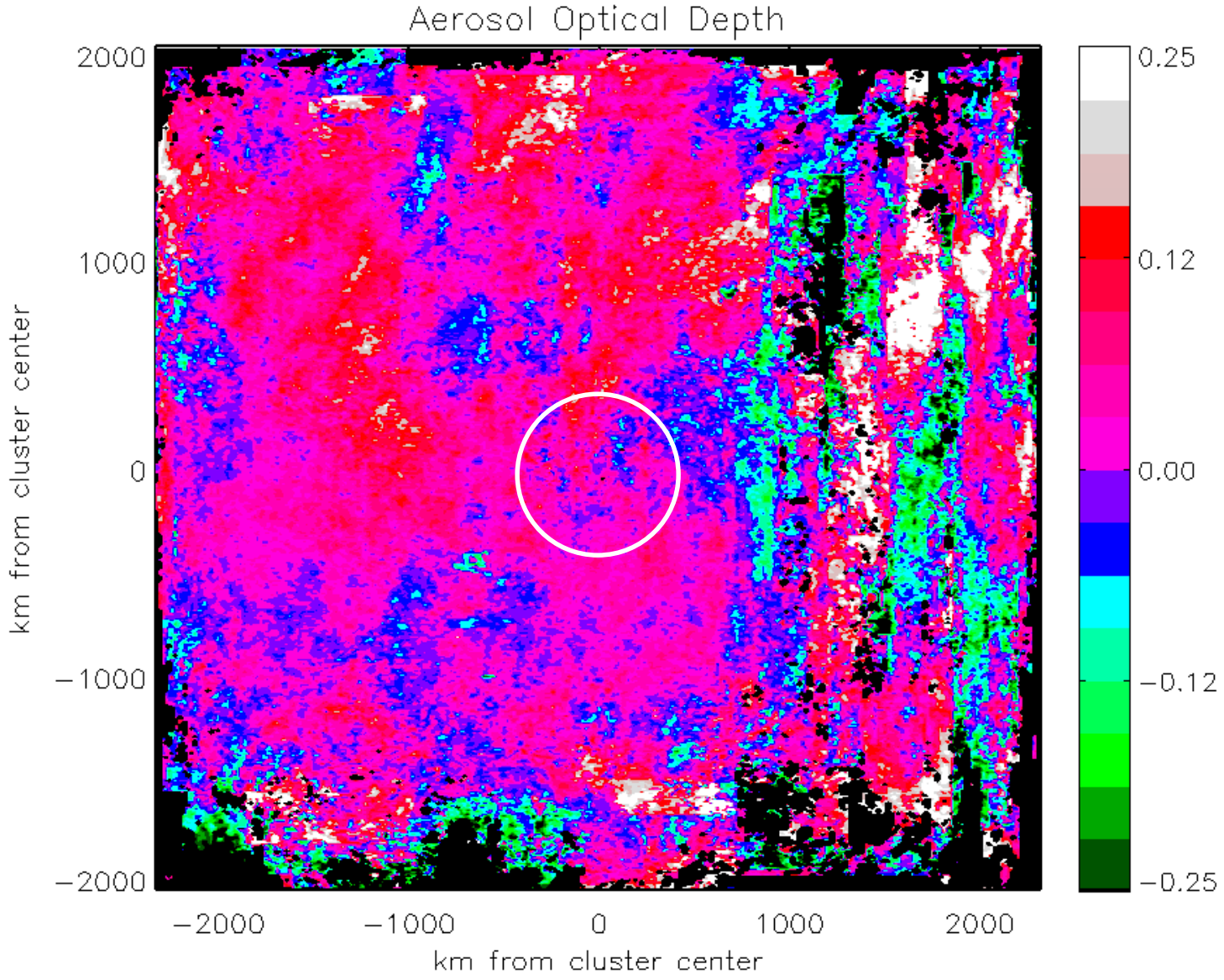
DATA

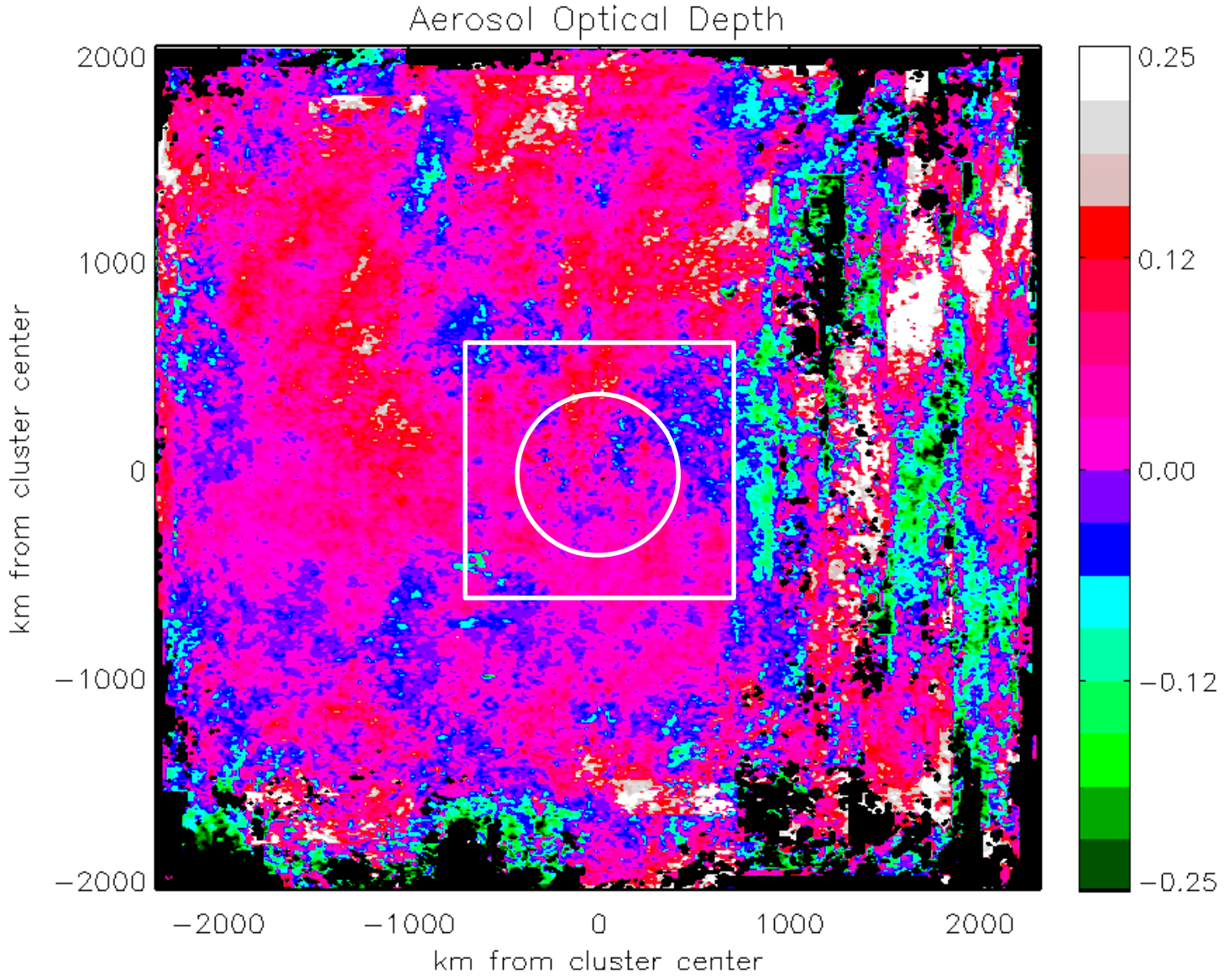
Other parameters

From MODIS or AIRS (Atmospheric Infrared Sounder).

AIRS: relative humidity, temperature, cloud top pressure.

RESULTS


Aerosol Optical Depth
2000
1000
0
−1000
−2000
km from cluster center
−2000
−1000
0
1000
2000
km from cluster center
0.25
0.12
0.00
−0.12
−0.25


Aerosol Optical Depth
2000
1000
0
−1000
−2000
km from cluster center
−2000
−1000
0
1000
2000
km from cluster center
0.25
0.12
0.00
−0.12
−0.25

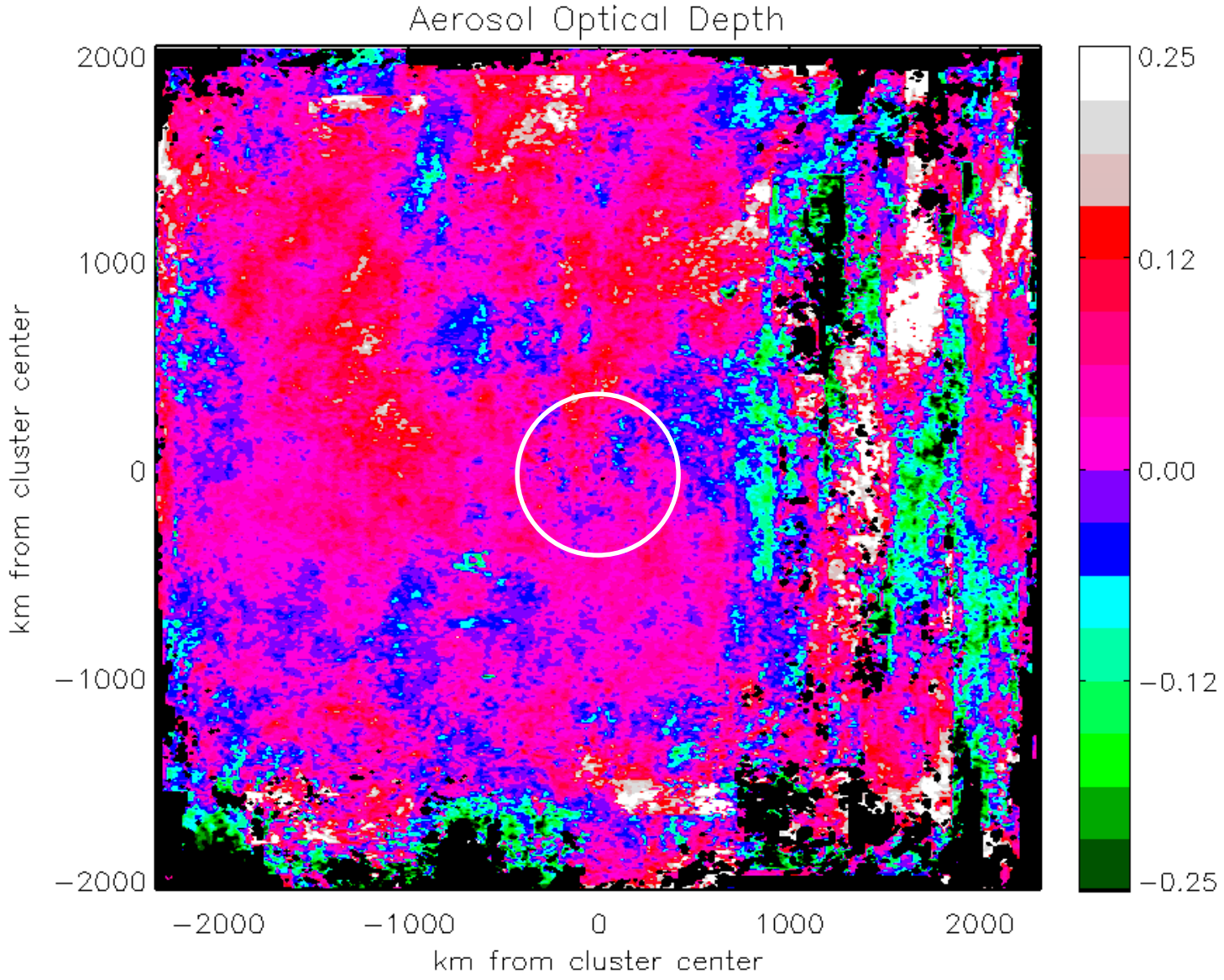
Aerosol Optical Depth In Clusters and the Nearby Environment (unitless)

Developers	Nondevelopers
.249	.197

Developers – 26% higher

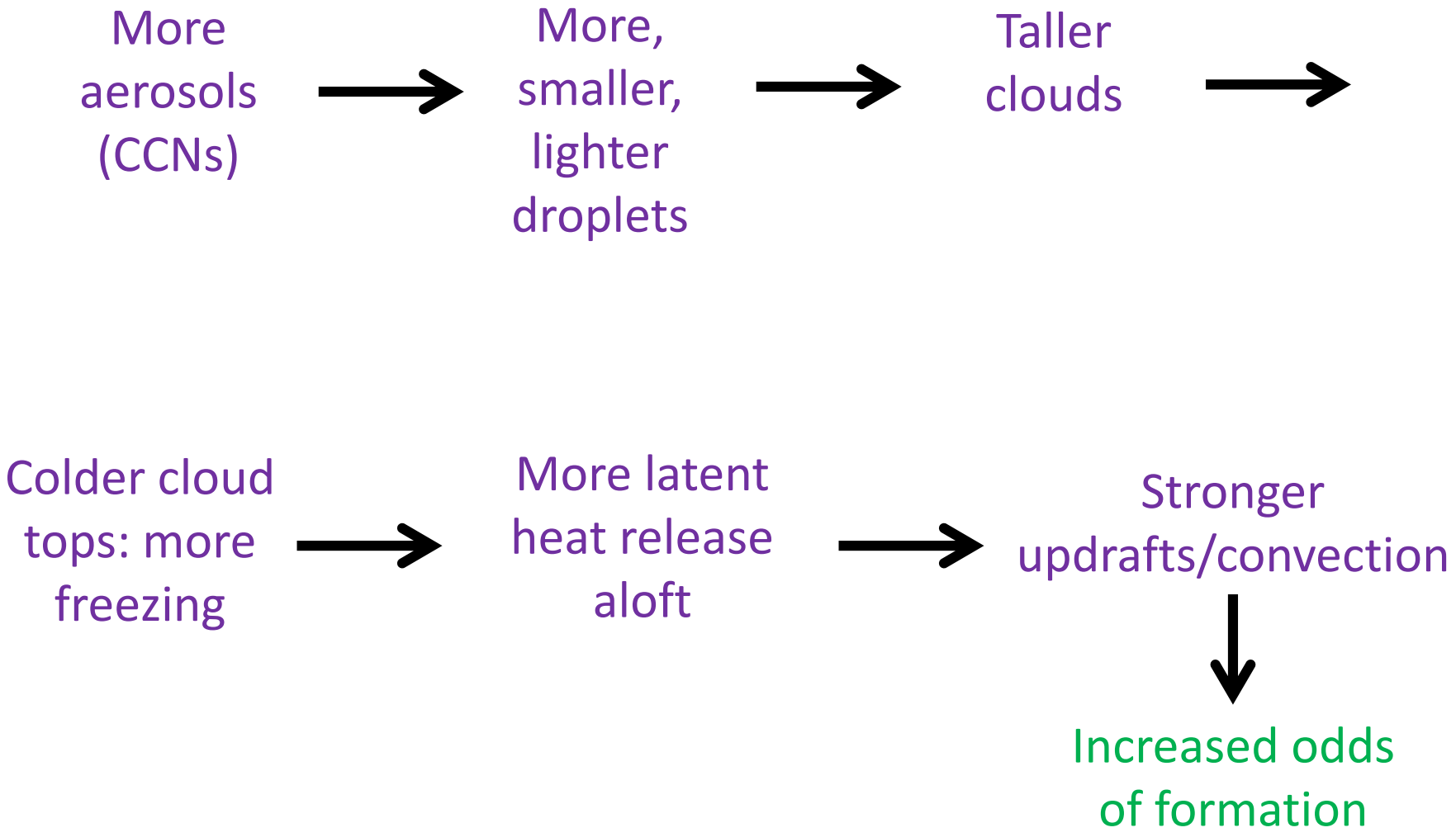
Statistical significance of all developer – nondeveloper differences is at least 99% (as determined by Student's t-test or the Mann Whitney U test), except for one, for which the significance is 94%.

STOP

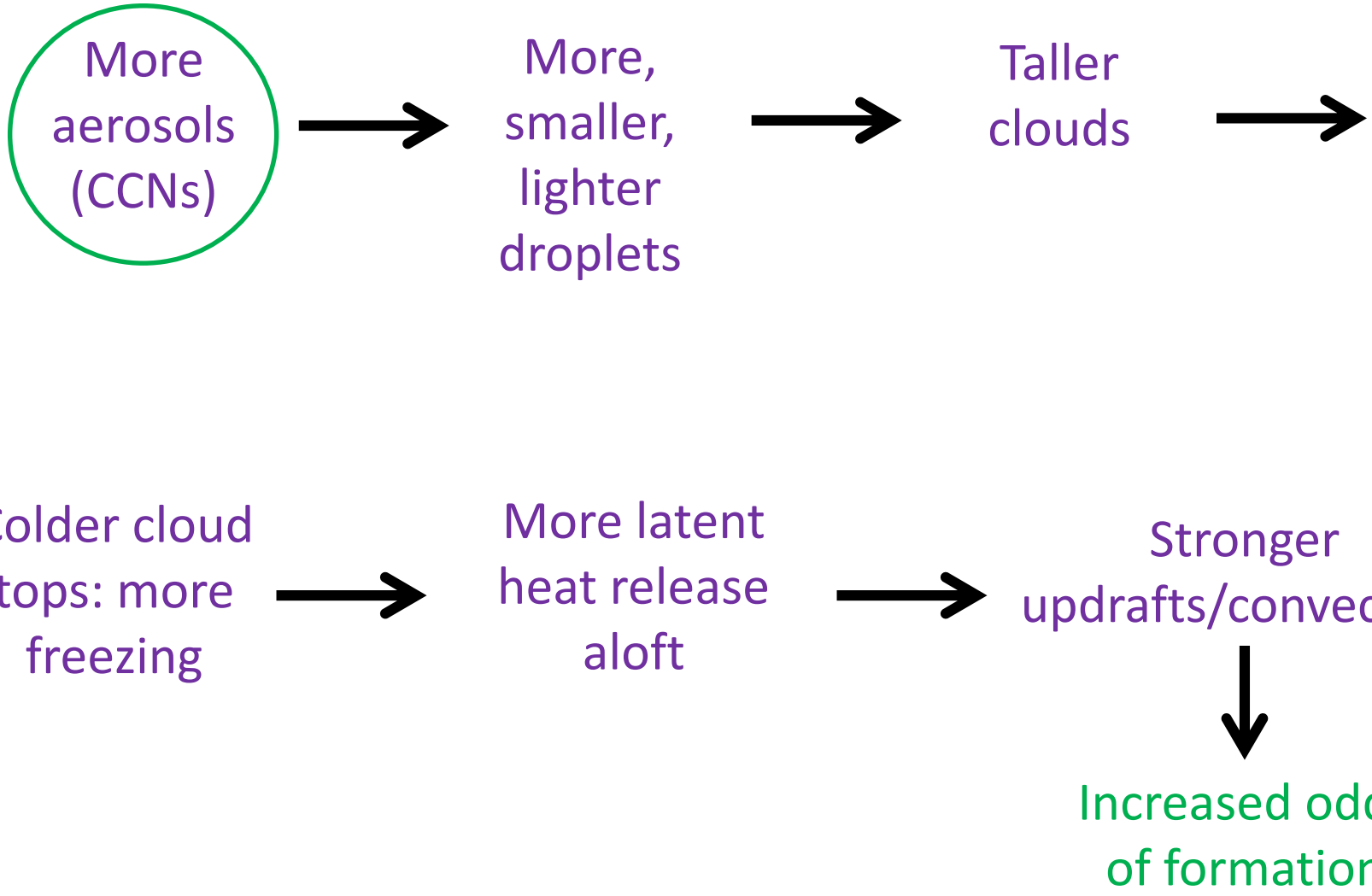

Aerosol Optical Depth
2000
1000
0
−1000
−2000
km from cluster center
−2000
−1000
0
1000
2000
km from cluster center
0.25
0.12
0.00
−0.12
−0.25

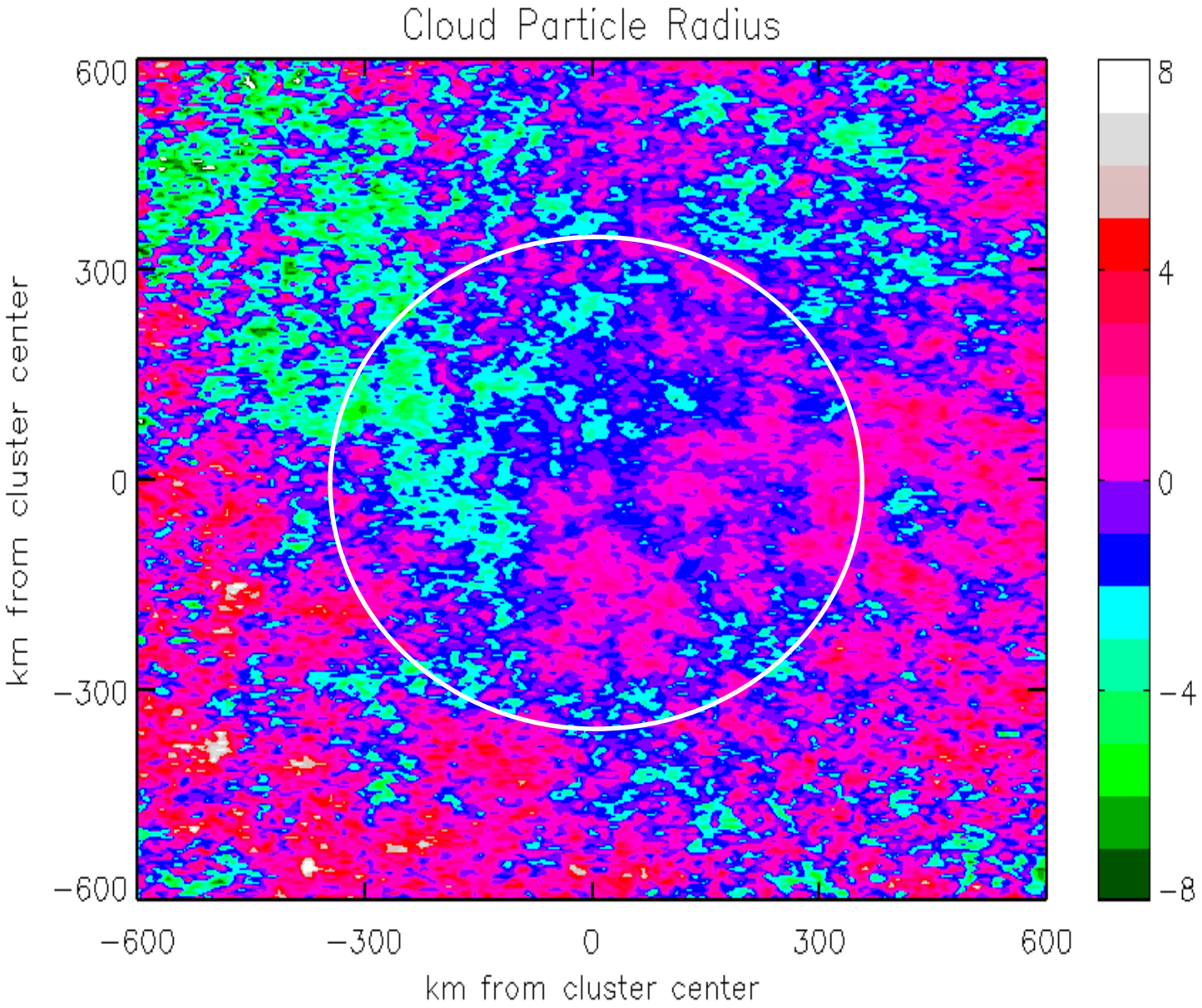
Strong evidence that abundant aerosols do not inhibit TC formation, and small amounts of aerosols are not conducive to TC formation.

More aerosols near cluster – Greater likelihood of TC formation?



More aerosols near cluster – Greater likelihood of TC formation?



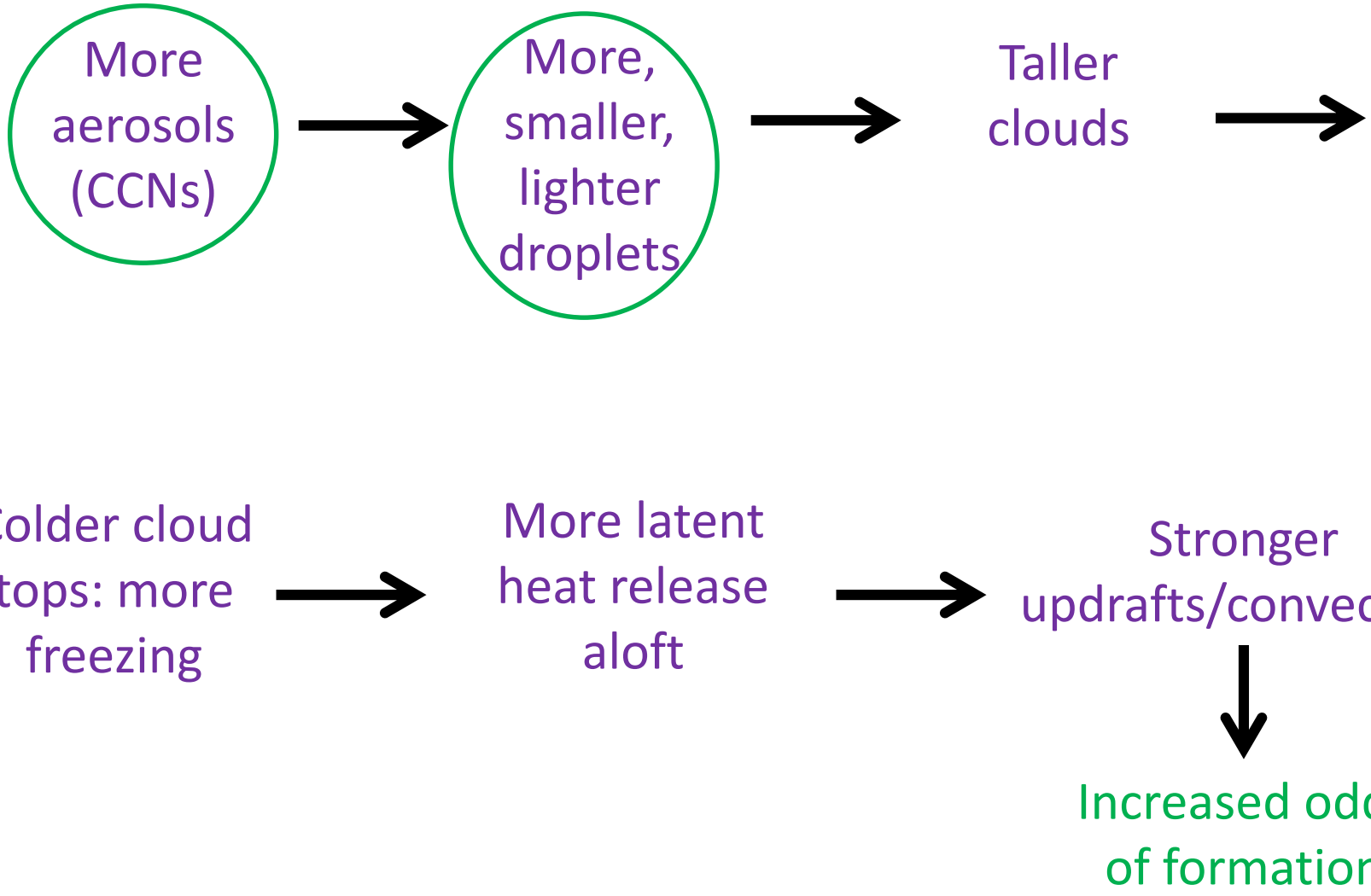

Cloud Particle Radius
600
300
0
−300
−600
km from cluster center
−600
−300
0
300
600
km from cluster center
8
4
0
−4
−8

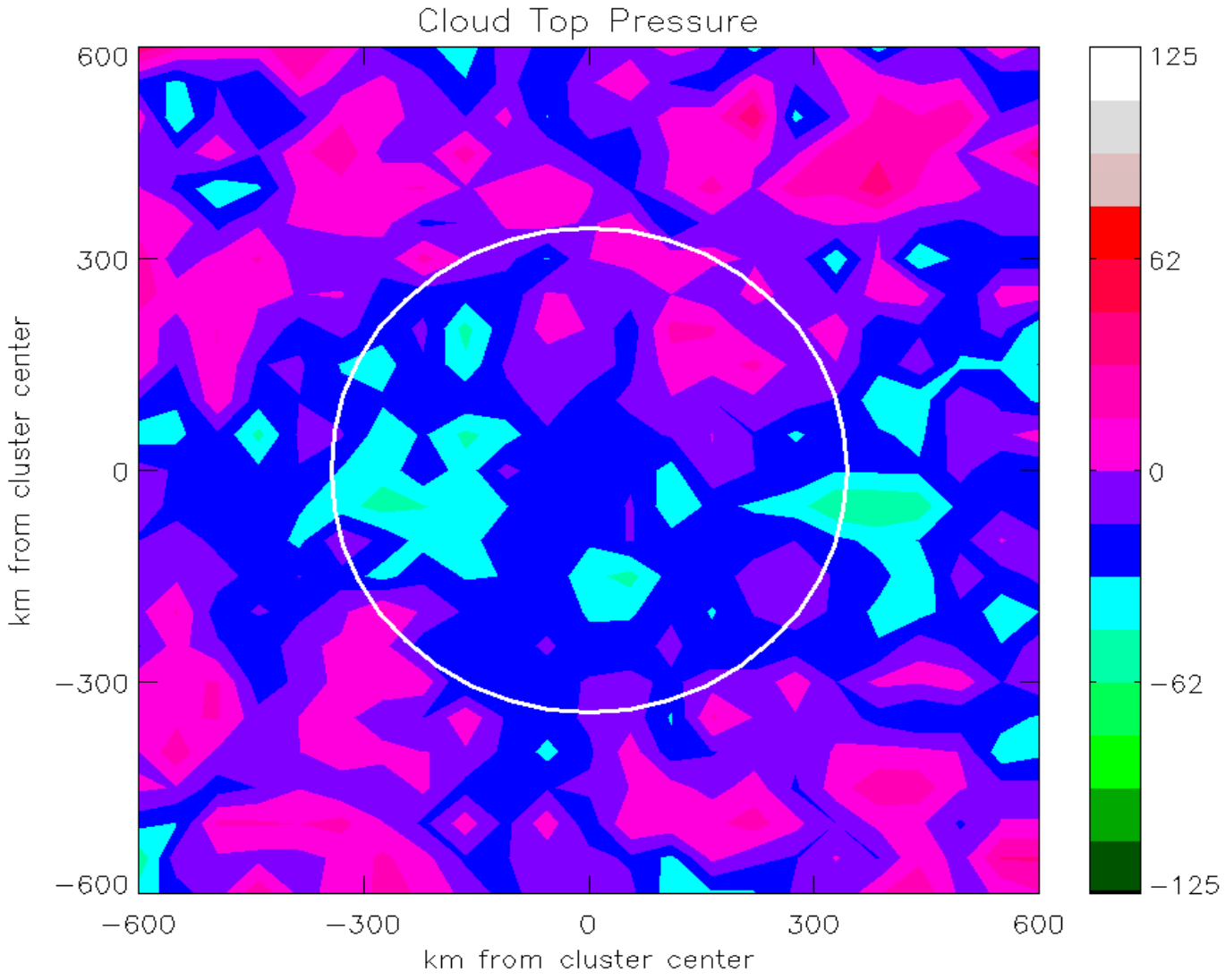
Cloud Particle Radius In Clusters (microns)

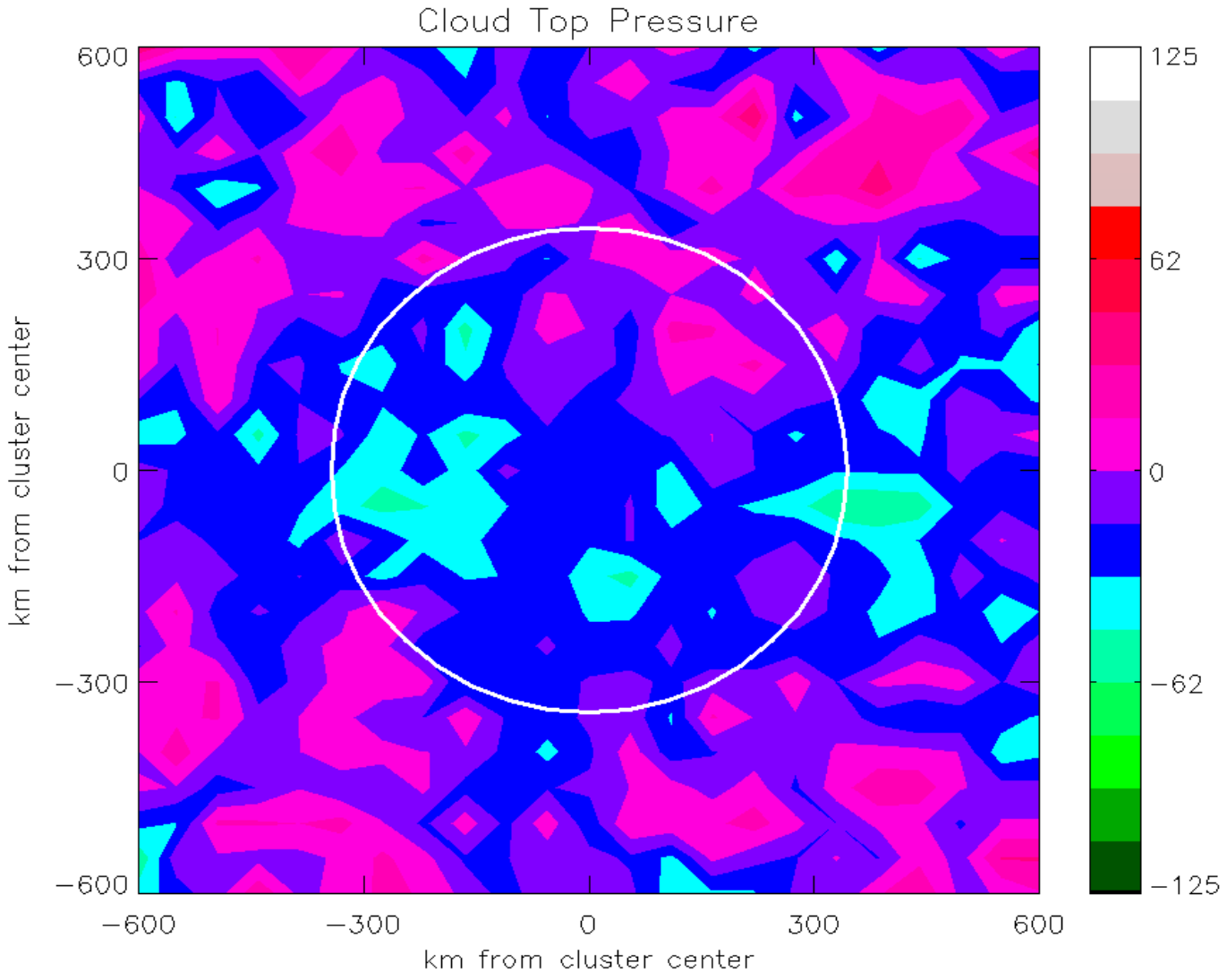
Developers	Nondevelopers
26.2	27.4

Developers – 5% (14%) smaller

More aerosols near cluster – Greater likelihood of TC formation?

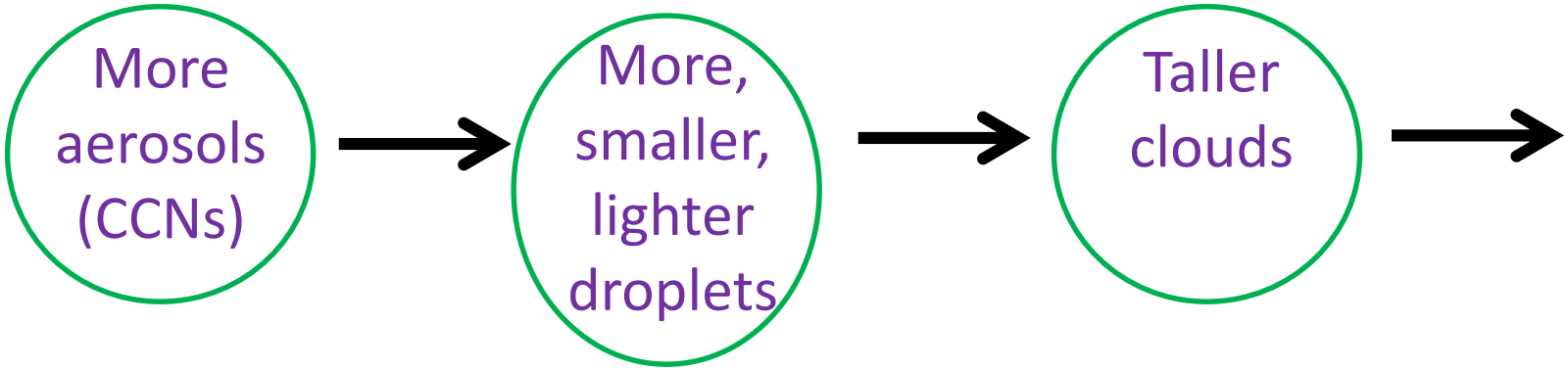


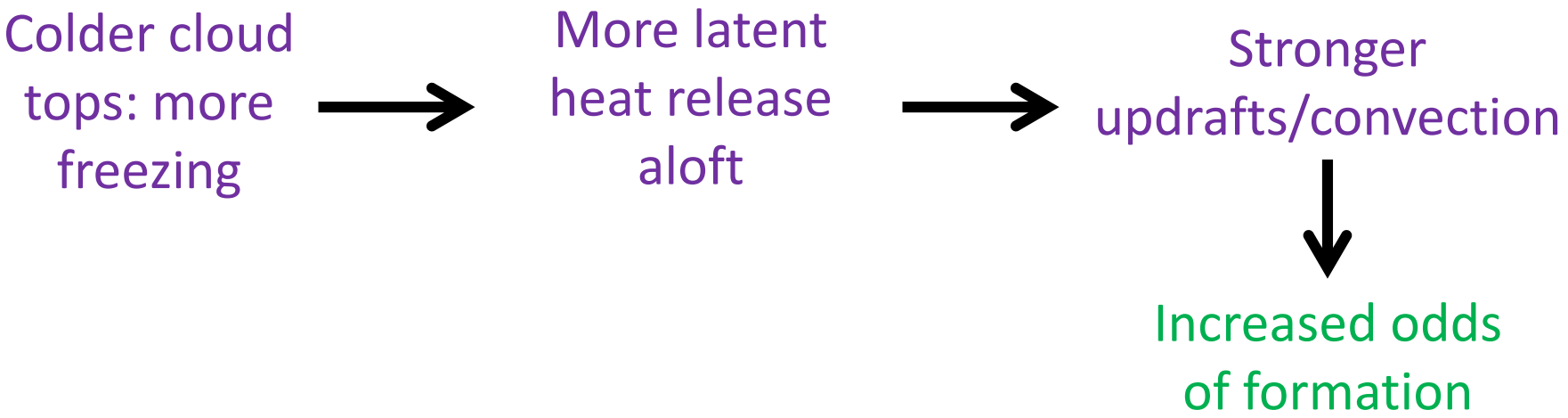

Cloud Top Pressure
600
300
0
−300
−600
km from cluster center
−600
−300
0
300
600
km from cluster center
125
62
0
−62
−125

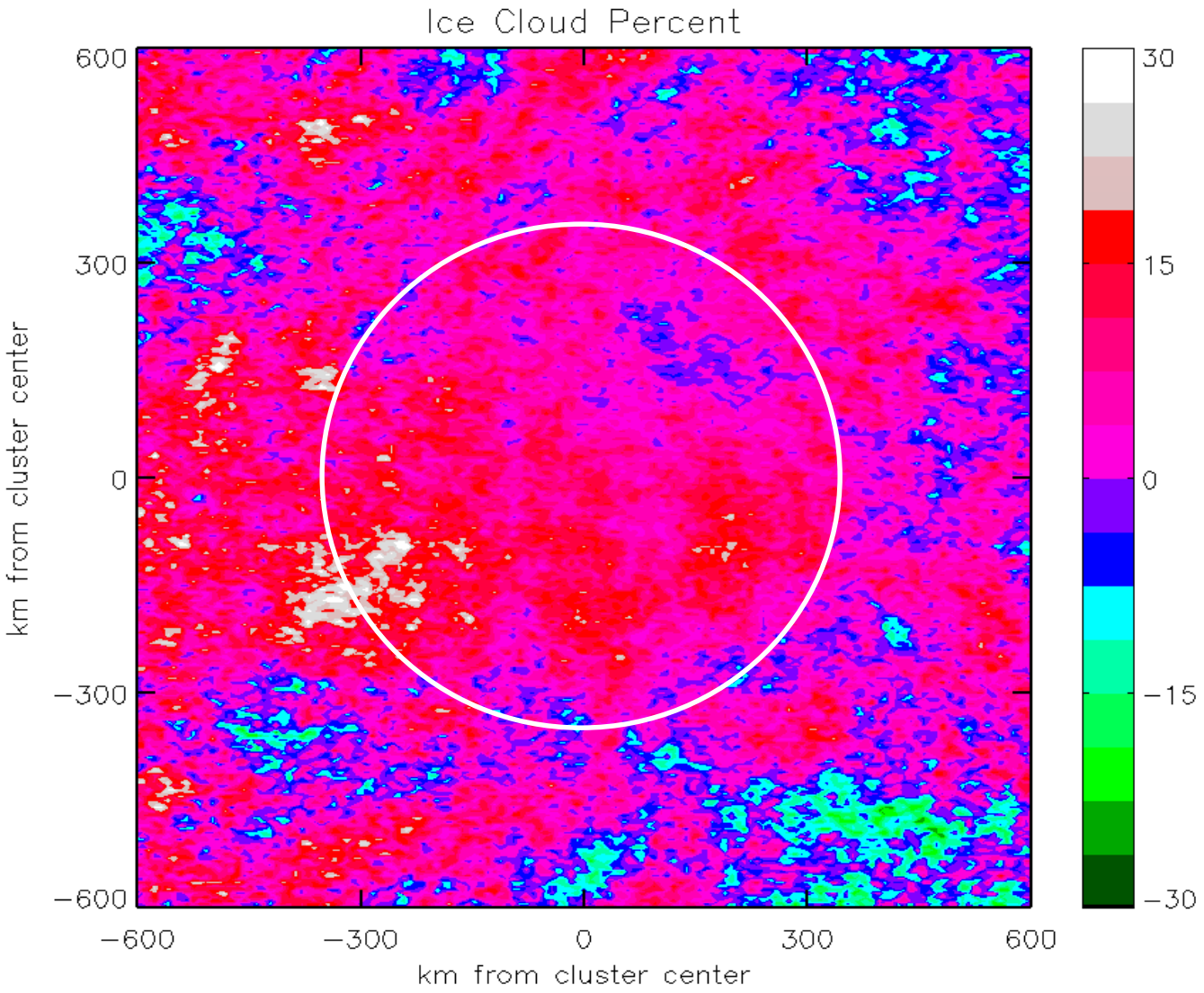


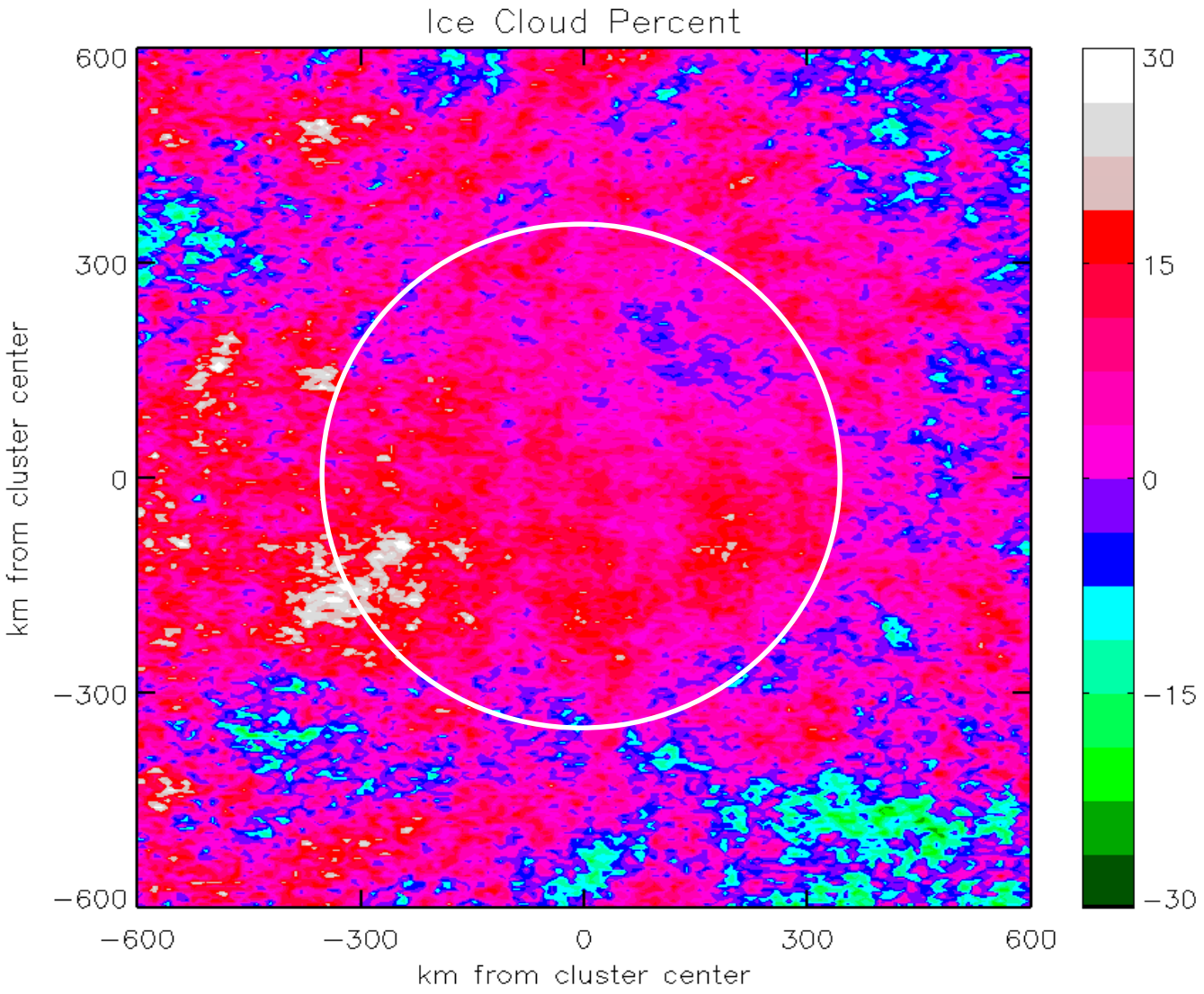
Developers – 17% taller

More aerosols near cluster – Greater likelihood of TC formation?



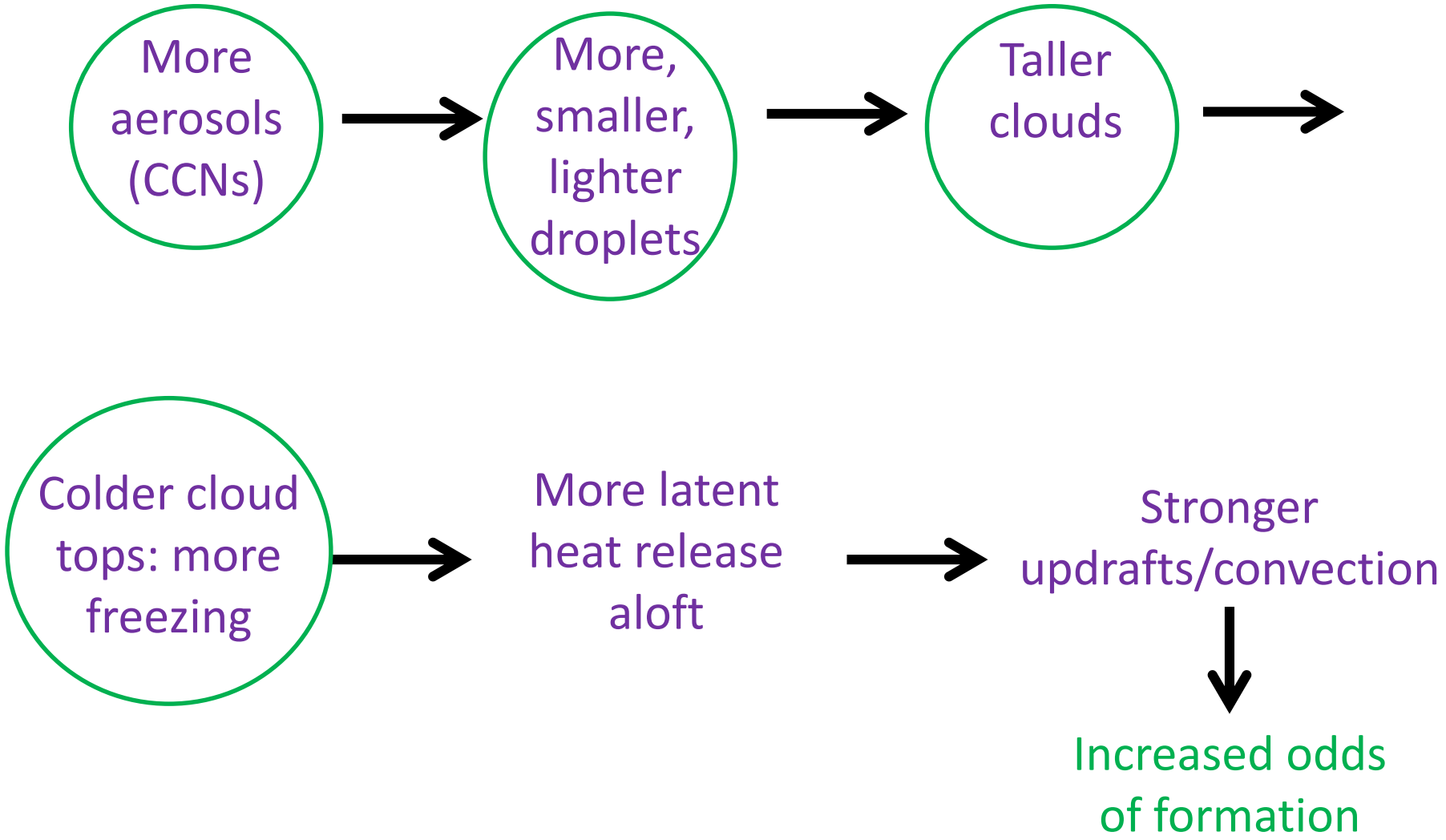


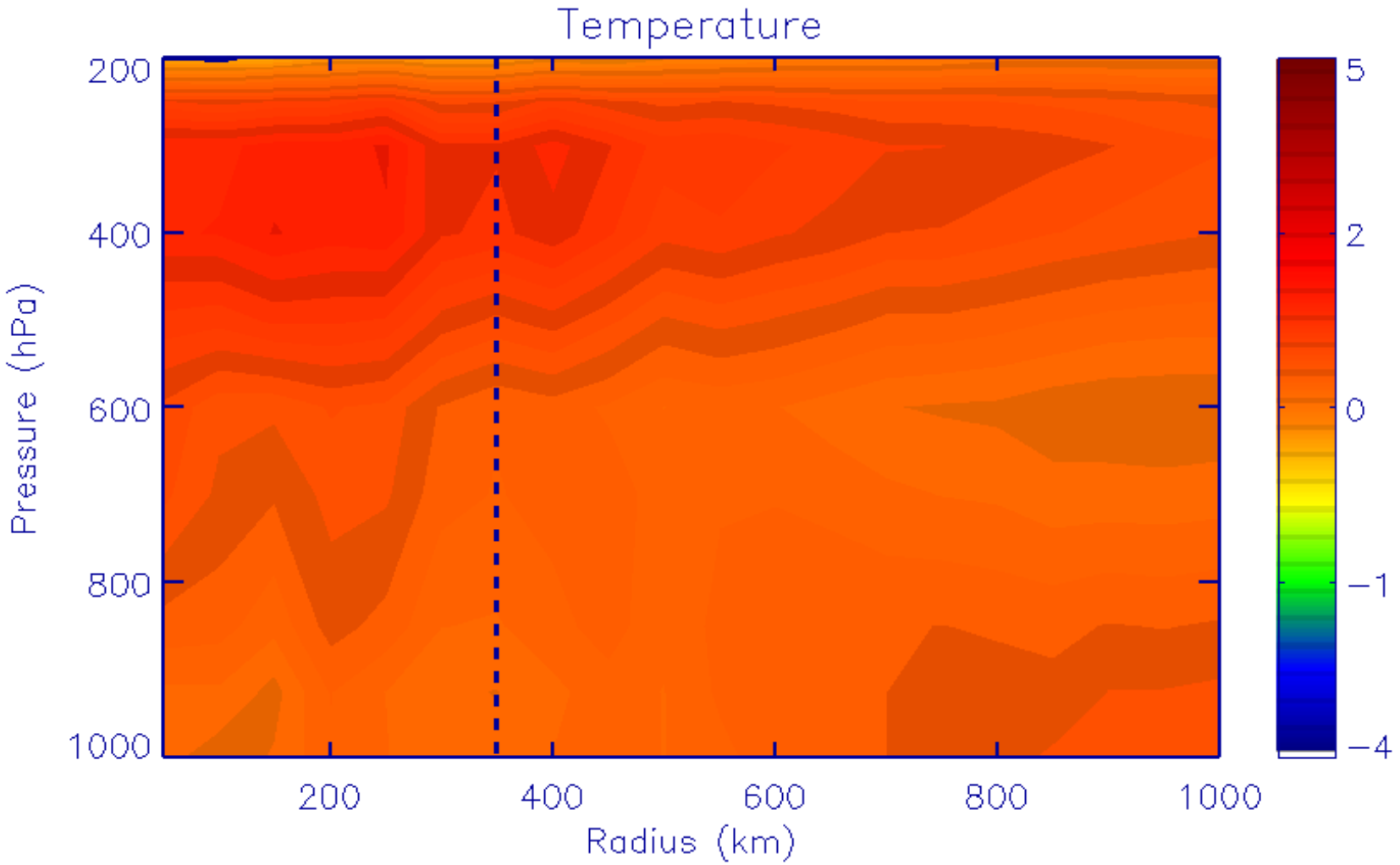

Ice Cloud Percent
600
300
0
−300
−600
km from cluster center
−600
−300
0
300
600
km from cluster center
30
15
0
−15
−30

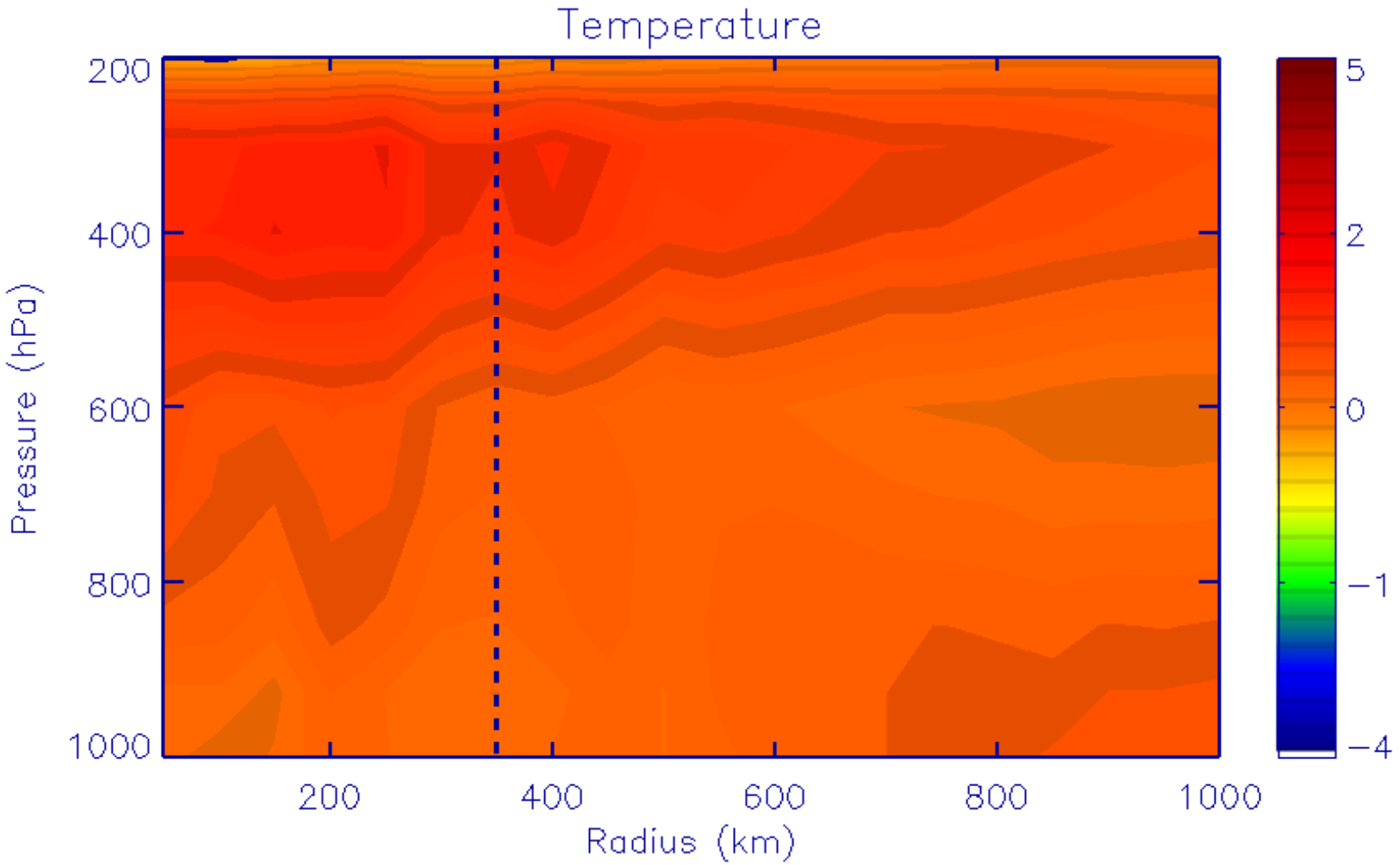


Developers – 11% higher

More aerosols near cluster – Greater likelihood of TC formation?

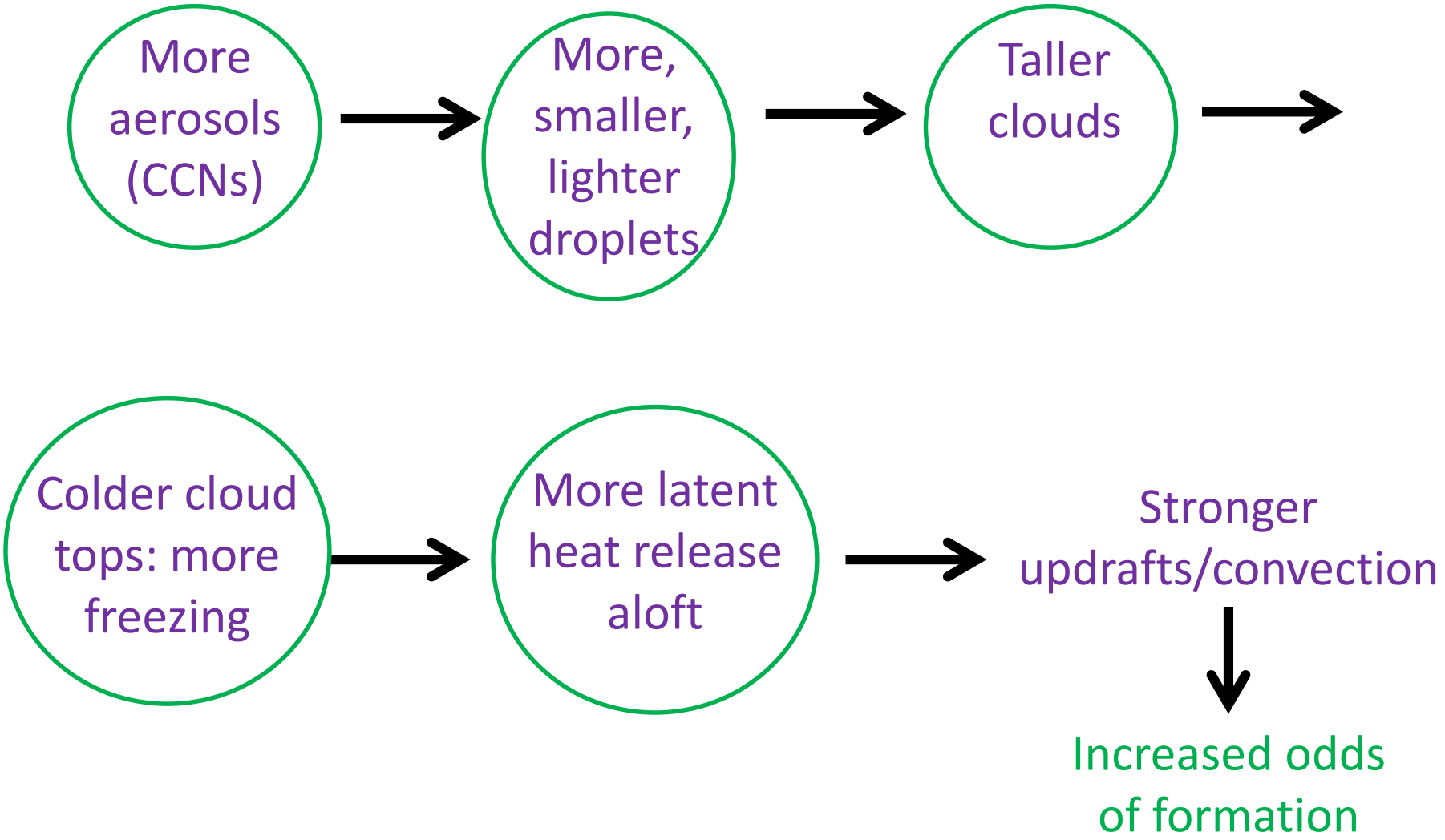


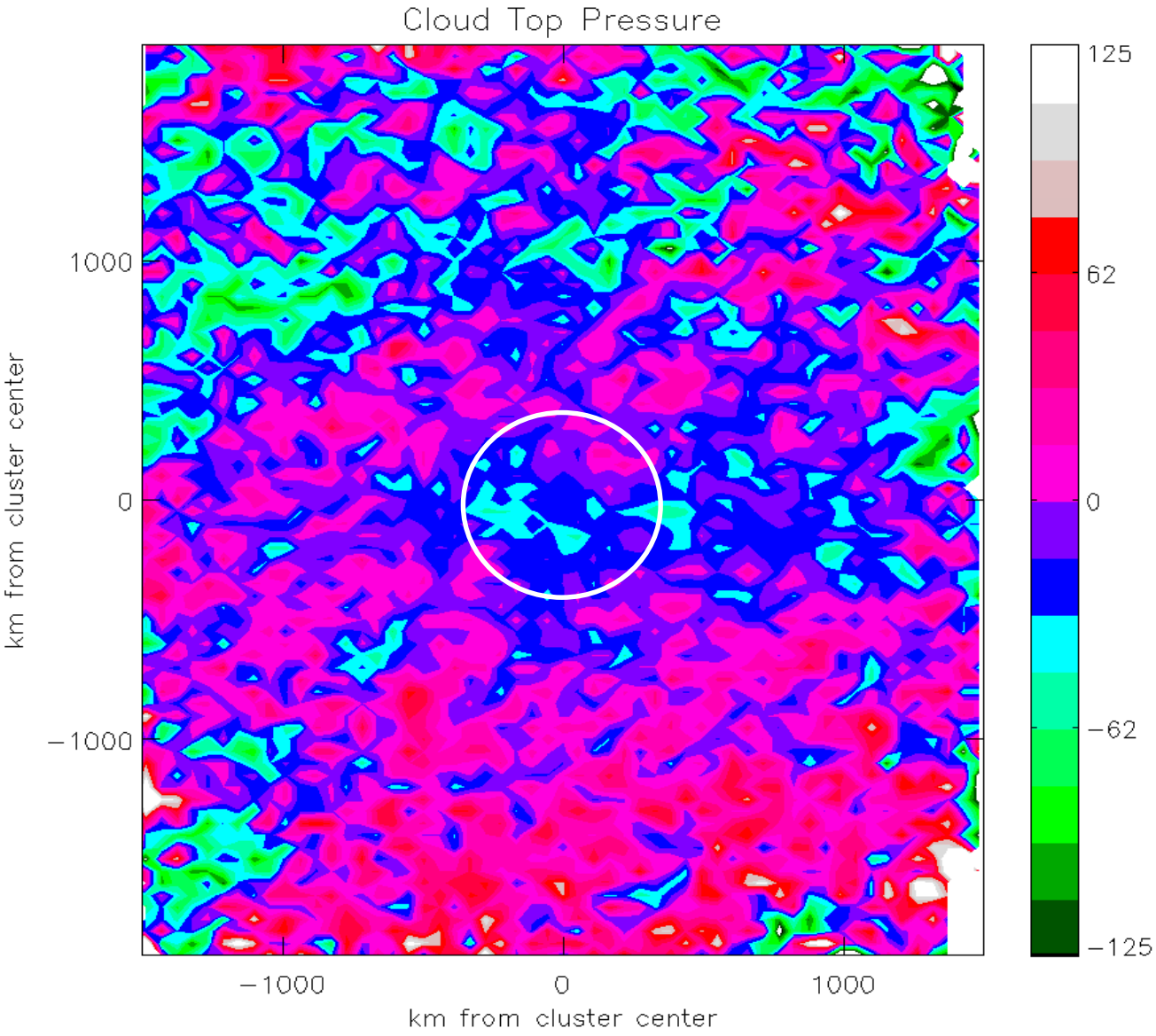

Temperature
200
400
600
800
1000
Pressure (hPa)
200
400
600
800
1000
Radius (km)
5
2
0
−1
−4



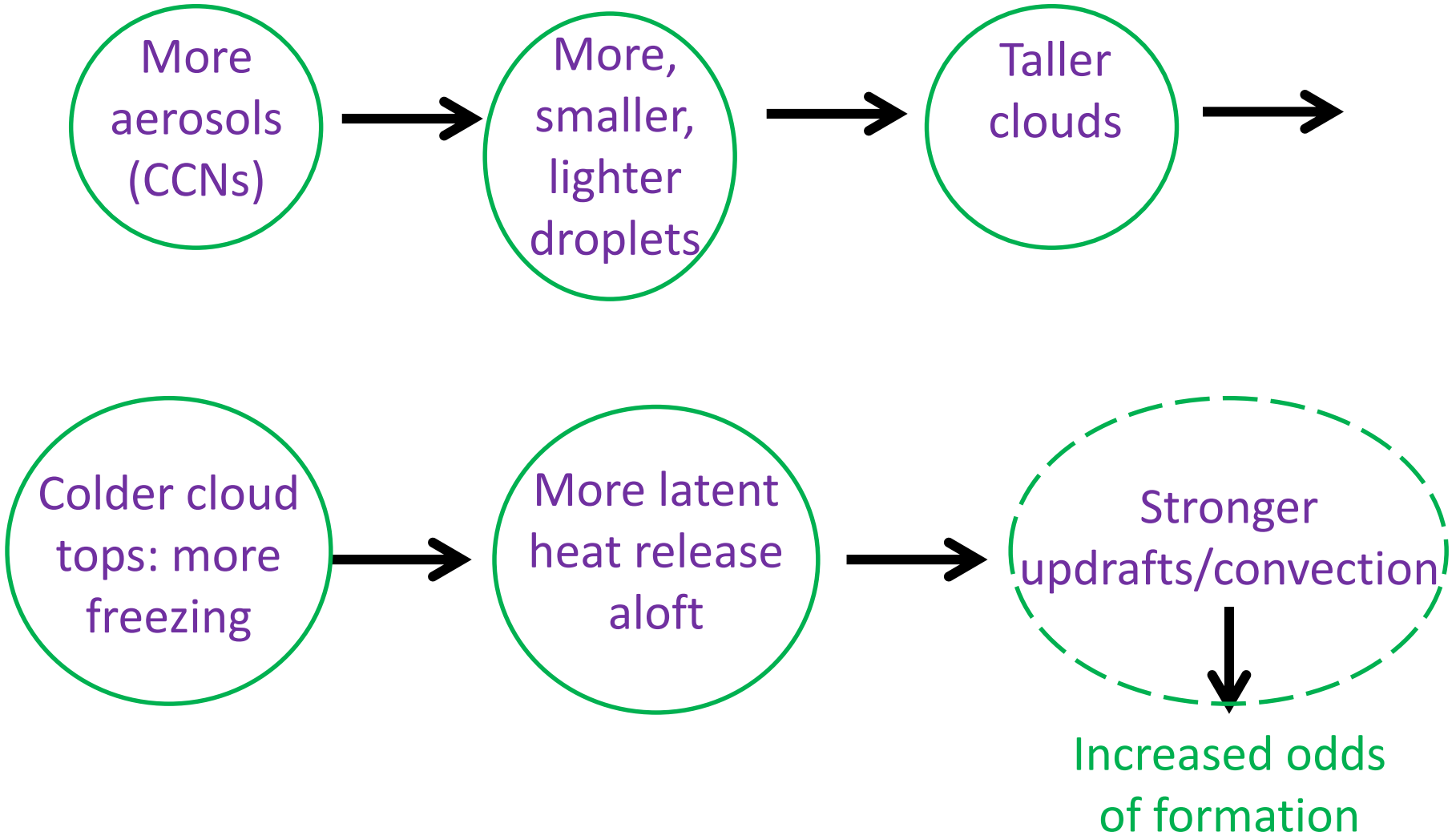
Developers – 89% more

More aerosols near cluster – Greater likelihood of TC formation?

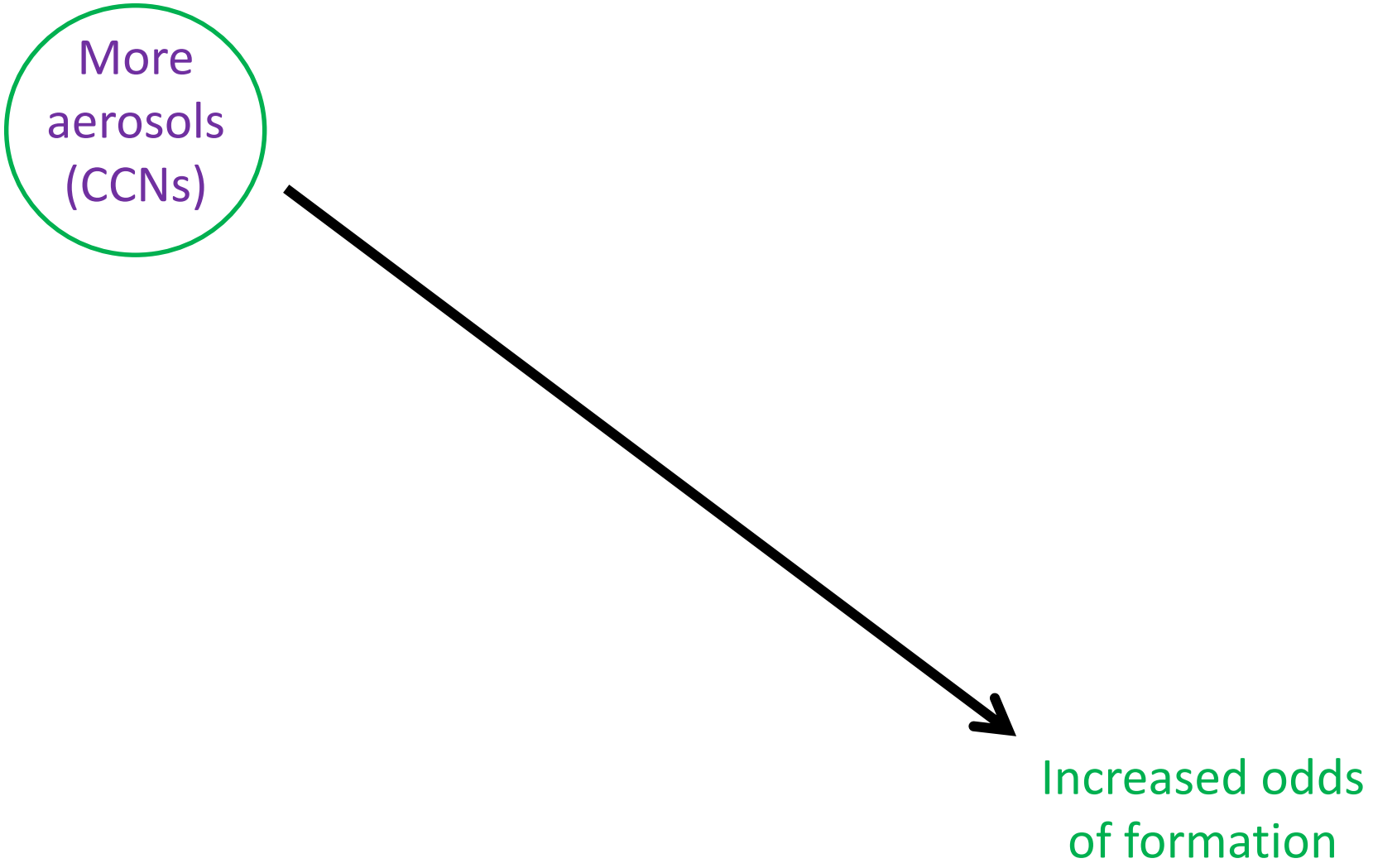



Cloud Top Pressure
1000
0
−1000
km from cluster center
−1000
0
1000
km from cluster center
125
62
0
−62
−125

More aerosols near cluster – Greater likelihood of TC formation?



More aerosols near cluster – Greater likelihood of TC formation?



The evidence is consistent with more invigoration of convection by aerosols in developers.

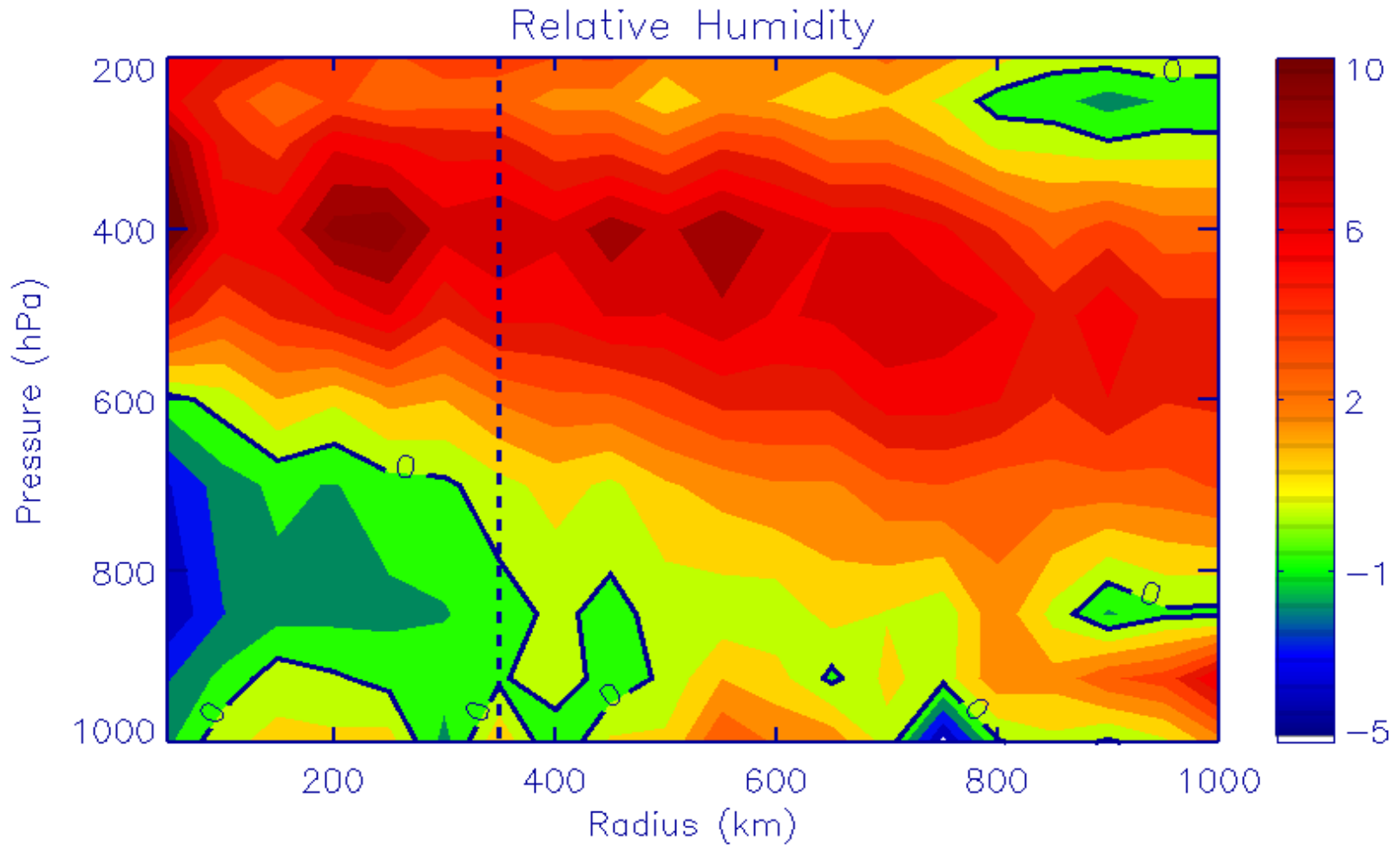
Too soon to conclude this definitely.

THE "BIG FIVE" ENVIRONMENTAL FACTORS IMPORTANT FOR TC FORMATION

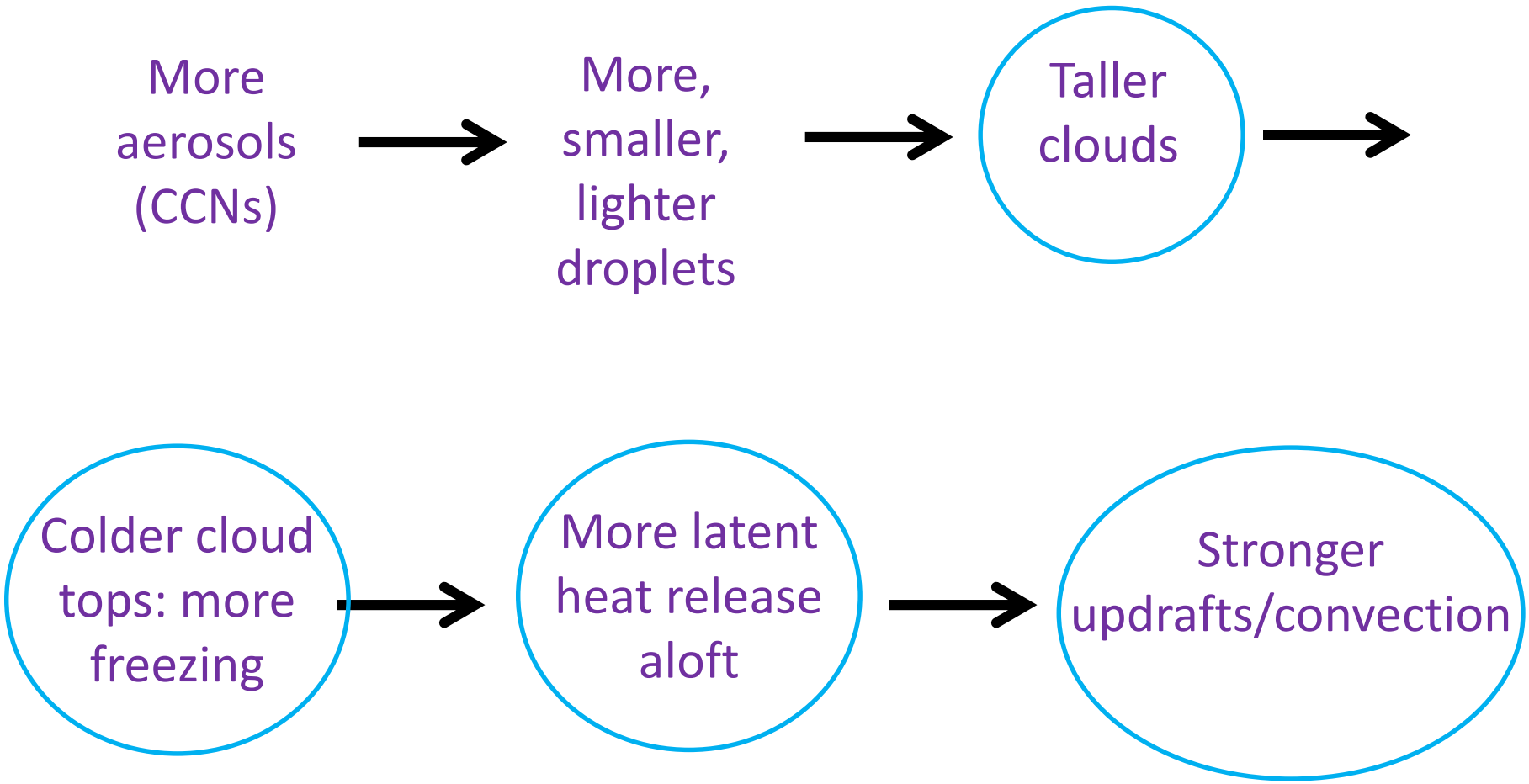
1. Warm sea surface temperature (26.5° C)
2. High mid-level humidity
3. Conditionally unstable (neutral?) lapse rates
4. Weak vertical wind shear
5. High low-level vorticity

THE "BIG FIVE" ENVIRONMENTAL FACTORS IMPORTANT FOR TC FORMATION

1. Warm sea surface temperature (26.5° C)
2. **High mid-level humidity**
3. Conditionally unstable (neutral?) lapse rates
4. Weak vertical wind shear
5. High low-level vorticity


Relative Humidity
Pressure (hPa)
200
400
600
800
1000
200
400
600
800
1000
Radius (km)
10
6
2
−1
−5
0

More aerosols – stronger convection

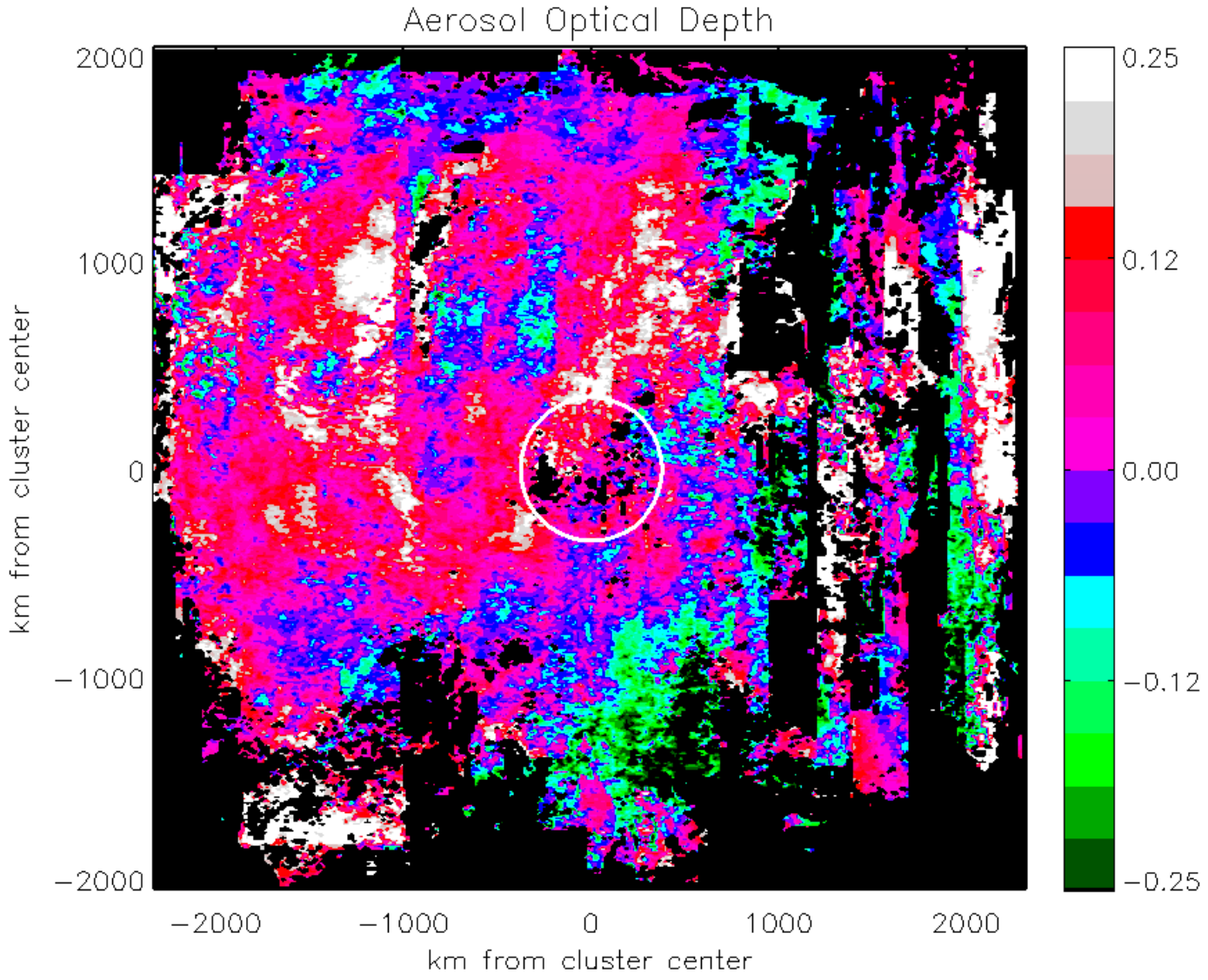


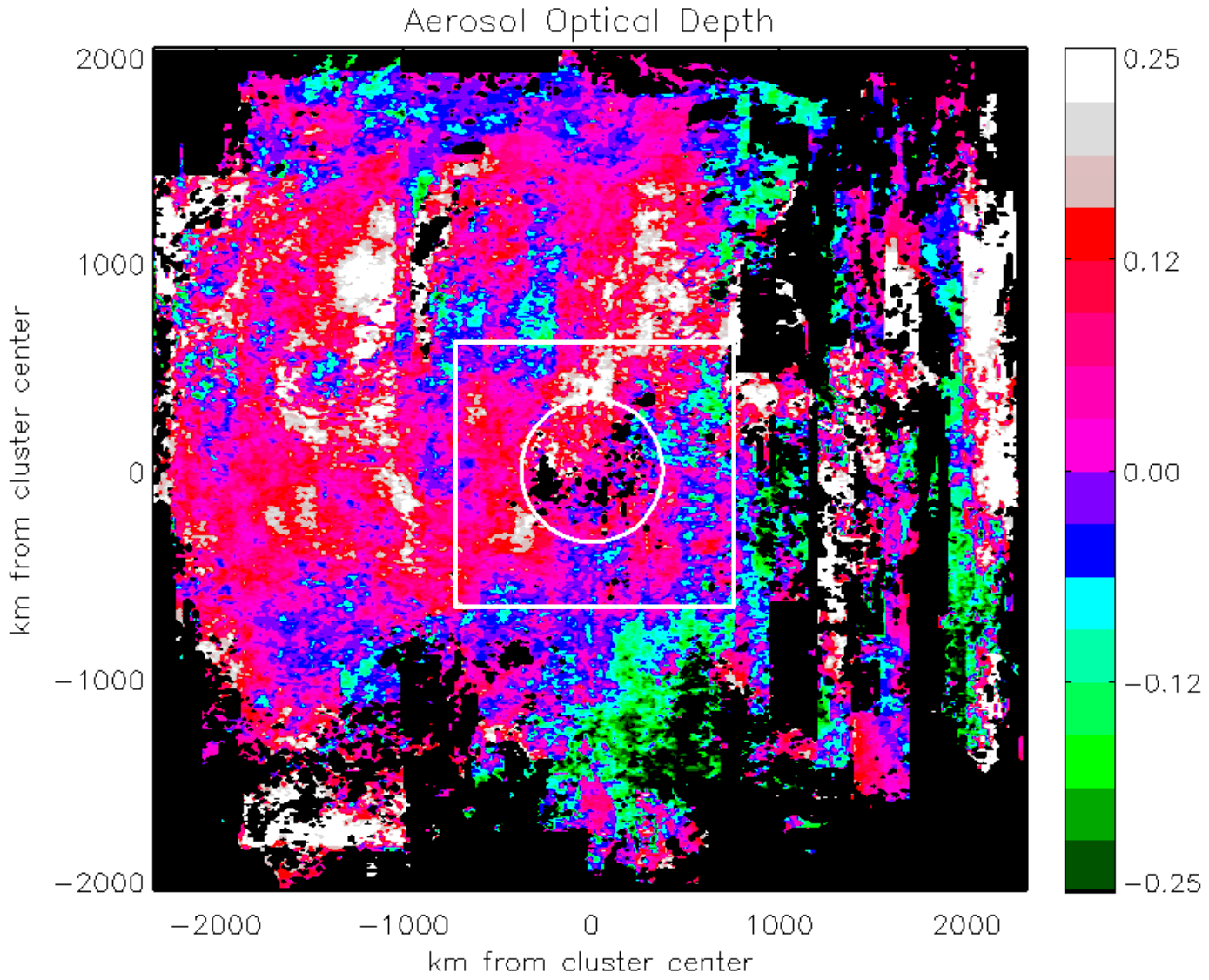
“Remove” effect of humidity

Subsets: all analyses were repeated but only developers and nondevelopers with similar environmental relative humidity (RH) were included:

- Environmental RH = RH at 500 hPa and 950-1000 km radii.
- The range of environmental RH for all cloud clusters is 8 to 70% -- only developers and nondevelopers with environmental RH between 37.5 and 46% were included.
- The “moderate RH developer” mean RH is only 1.73% higher than the “moderate RH nondeveloper” mean RH.

Do we still see evidence of convective invigoration by aerosols (do we see what we saw before) with the influence of humidity removed?


Aerosol Optical Depth
2000
1000
0
−1000
−2000
km from cluster center
−2000
−1000
0
1000
2000
km from cluster center
0.25
0.12
0.00
−0.12
−0.25

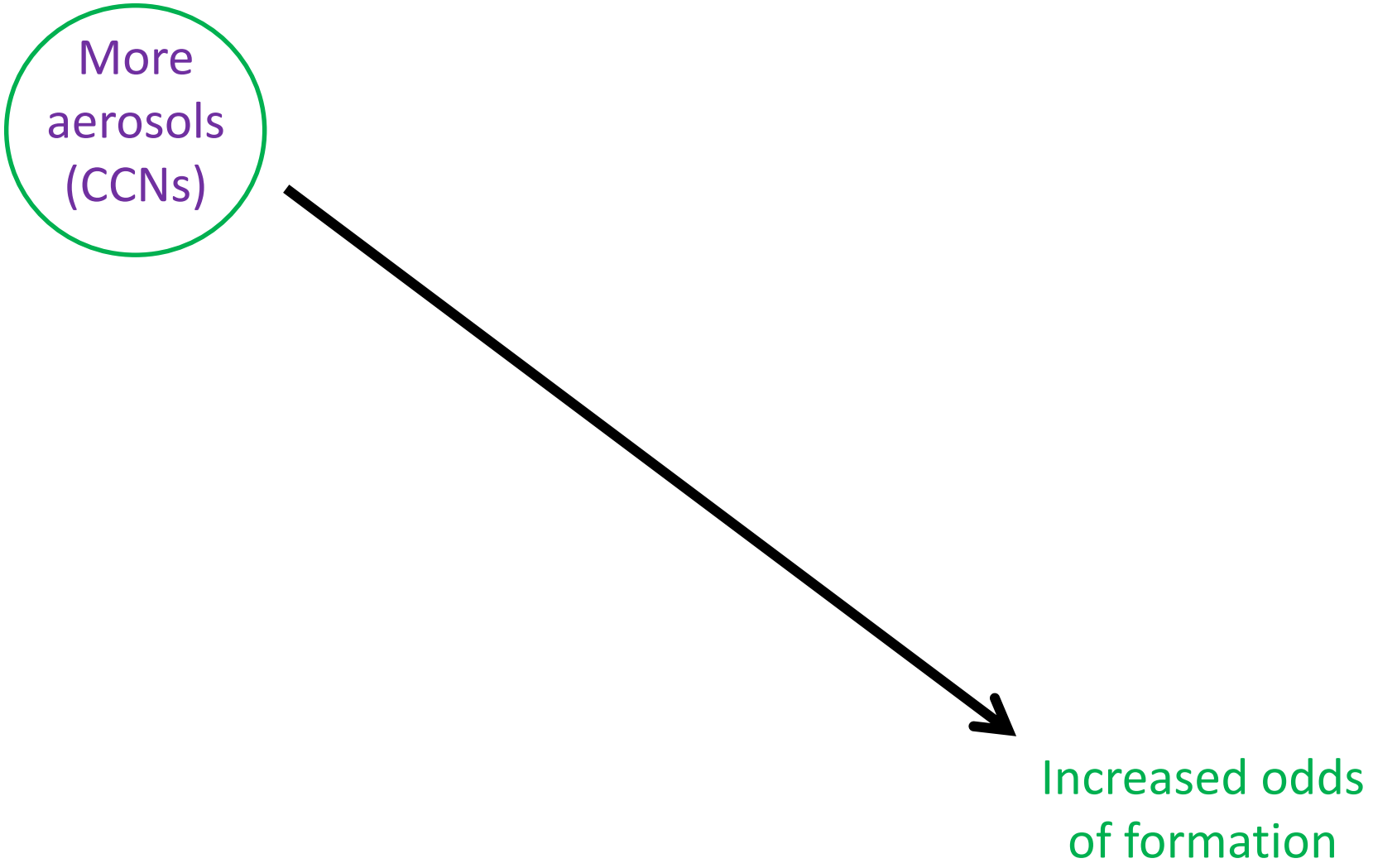


Developers – 54% higher

	Percent Difference Between Means All Clusters	Percent Difference Between Means Moderate RH Clusters
AOD	26	54
Cloud Particle Radius	-5 (-14)	-7 (-21)
Cloud Top Pressure	-17	-15
Ice Cloud Percentage	11	10
Latent Heating Proxy	89	213

Therefore, when the influence of humidity is removed, developers still show stronger signs of convective invigoration by aerosols than nondevelopers.

More aerosols near cluster – Greater likelihood of TC formation?

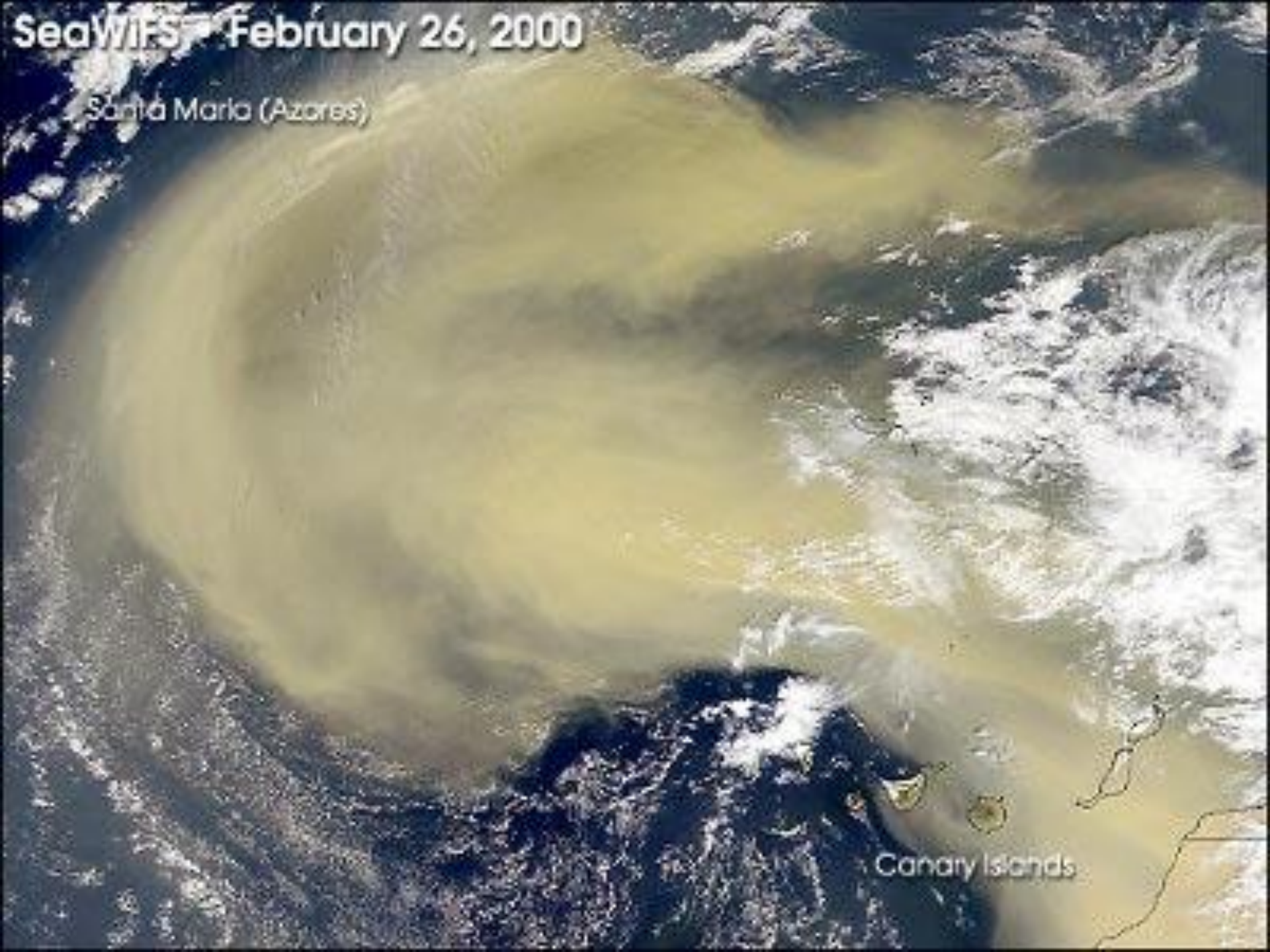


THE "BIG FIVE" ENVIRONMENTAL FACTORS IMPORTANT FOR TC FORMATION

1. Warm sea surface temperature (26.5° C)
2. High mid-level humidity
3. Conditionally unstable (neutral?) lapse rates
4. Weak vertical wind shear
5. High low-level vorticity

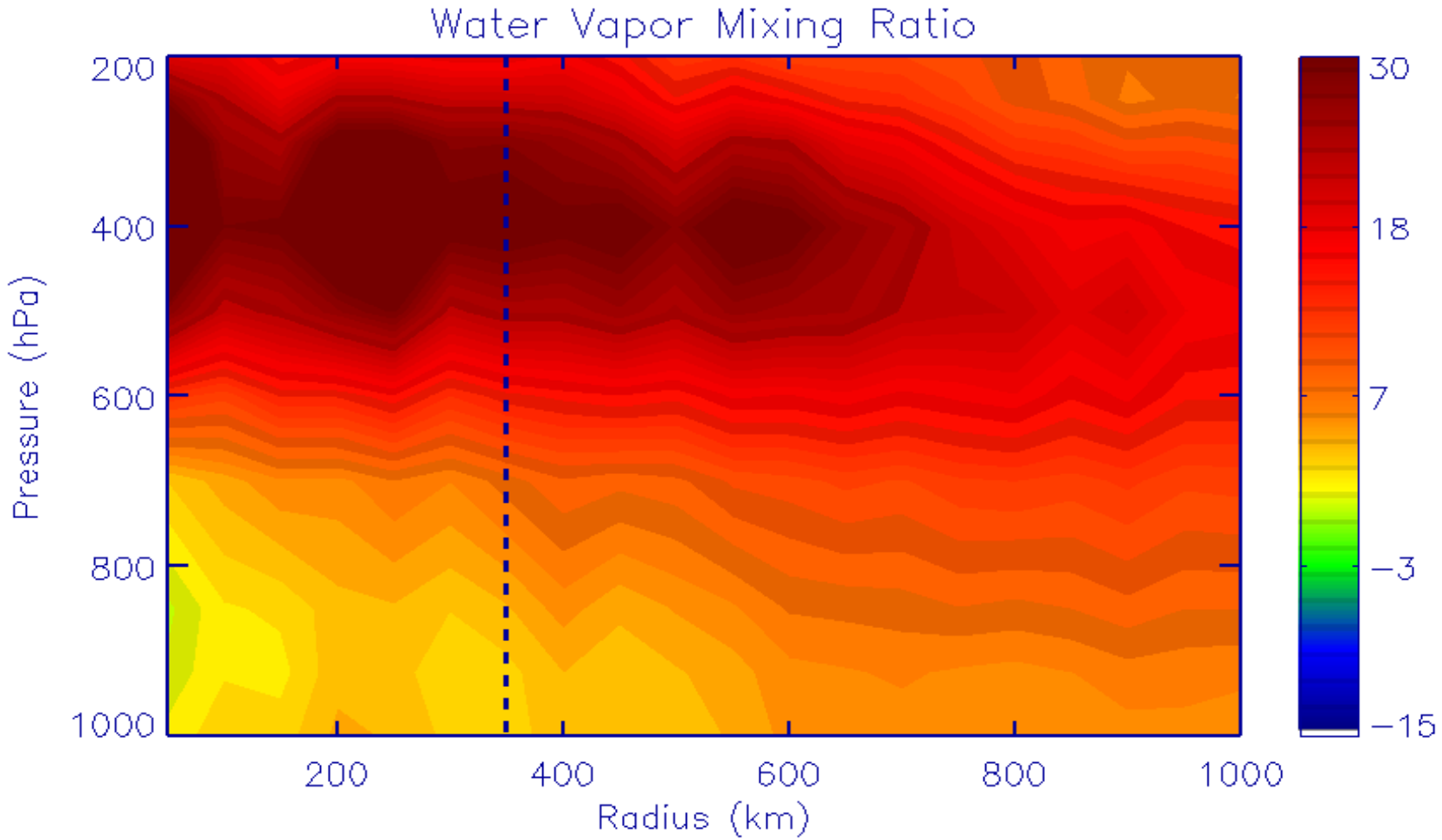
Where do the aerosols come from?

The Saharan Air Layer (SAL) is a natural suspect

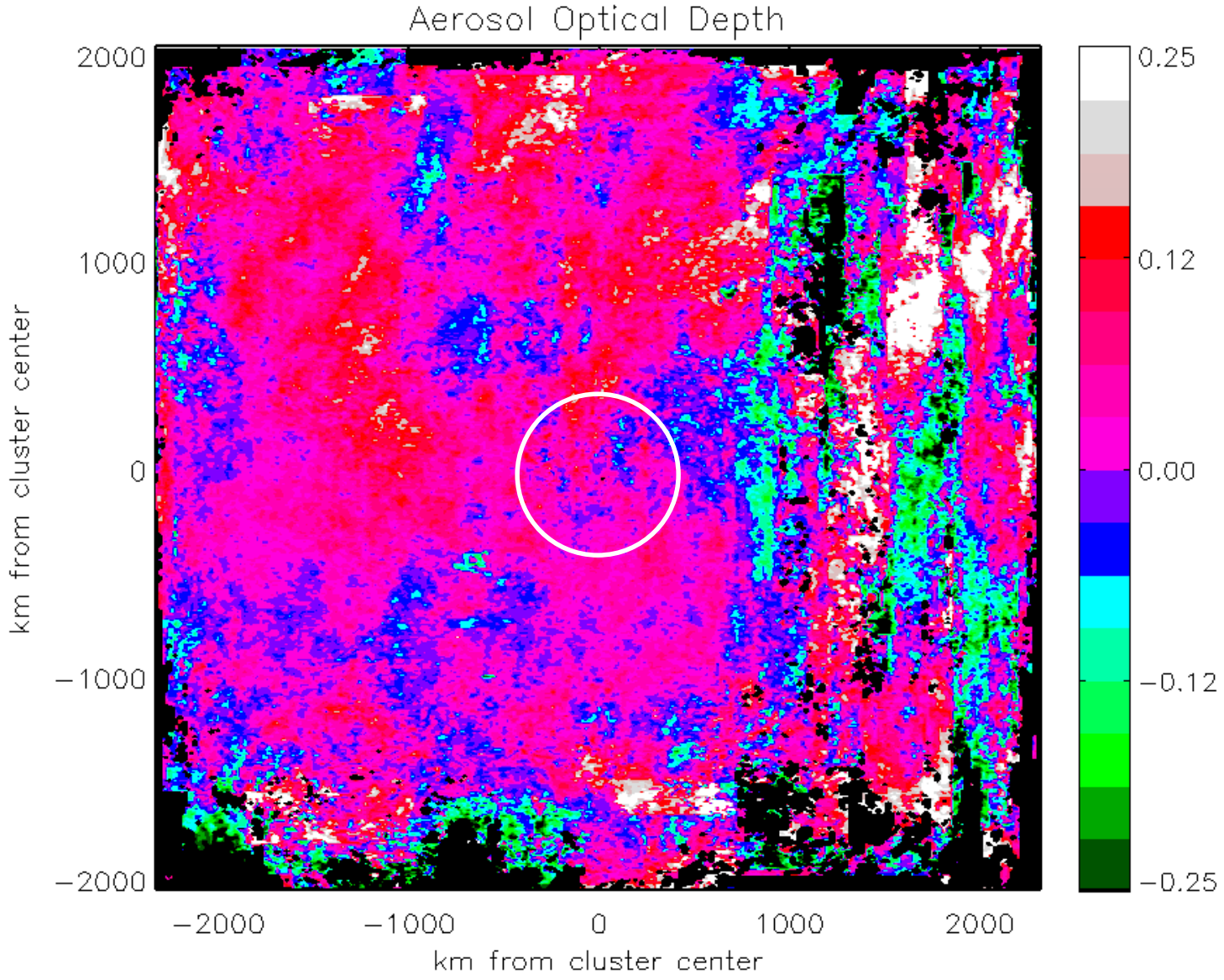

SeaWiFS February 26, 2000
Santa Maria (Azores)
Canary Islands

Finding evidence of the SAL :

1. Many aerosols
2. Warm Temperatures at midlevels
3. Dry at midlevels


Water Vapor Mixing Ratio
Pressure (hPa)
200
400
600
800
1000
200
400
600
800
1000
Radius (km)
30
18
7
−3
−15

- From this data, one might conclude that the developers were closer to the SAL than nondevelopers. However, the air to the south of the SAL is extra moist…


Aerosol Optical Depth
2000
1000
0
−1000
−2000
km from cluster center
−2000
−1000
0
1000
2000
km from cluster center
0.25
0.12
0.00
−0.12
−0.25

Things I didn't have time to talk about

- We also looked at "fine mode" AOD, and found similar results.

- Thoroughly investigated whether the high humidity near the developers biased the AOD data, and we are very sure the humidity was not high enough to bias the results.

CONCLUSIONS

1. Aerosol concentrations are higher in the environment of cloud clusters that development into TCs compared to the environment of clusters that do not develop.
2. Abundant aerosols do not inhibit a cluster from developing into a TC.
3. Developers show evidence of experiencing all 5 steps associated with convective invigoration by aerosols.
4. Results are consistent with the idea that high aerosol content increases the chance a cloud cluster will develop into a TC by invigorating its convection (but we cannot conclude that definitely).

CONCLUSIONS

5. The influence of aerosols on TC formation appears to be independent from that of humidity.

6. The high aerosol content near developers **may** come from the SAL.

IMPLICATIONS

Prediction of TC formation

THE "BIG FIVE" ENVIRONMENTAL FACTORS IMPORTANT FOR TC FORMATION

1. Warm sea surface temperature (26.5° C)
2. High mid-level humidity
3. Conditionally unstable (neutral?) lapse rates
4. Weak vertical wind shear
5. High low-level vorticity

THE "BIG SIX?" ENVIRONMENTAL FACTORS IMPORTANT FOR TC FORMATION

1. Warm sea surface temperature (26.5° C)
2. High mid-level humidity
3. Conditionally unstable (neutral?) lapse rates
4. Weak vertical wind shear
5. High low-level vorticity
6. **High aerosol levels?**

FUTURE WORK

- Remove influence of sea surface temperature, vertical wind shear, lapse rates, and low-level vorticity.
- Examine clusters between 2005 – present.
- Logistic multi-regression using all environmental parameters.
- Examine storms in the Pacific and Indian oceans.

Thanks to:

Eric Fetzer, Rob Fovell

The results discussed in this seminar have been submitted to Geophysical Research Letters.

Chris Collimore
ccollimore@ccny.cuny.edu

This work was supported by:

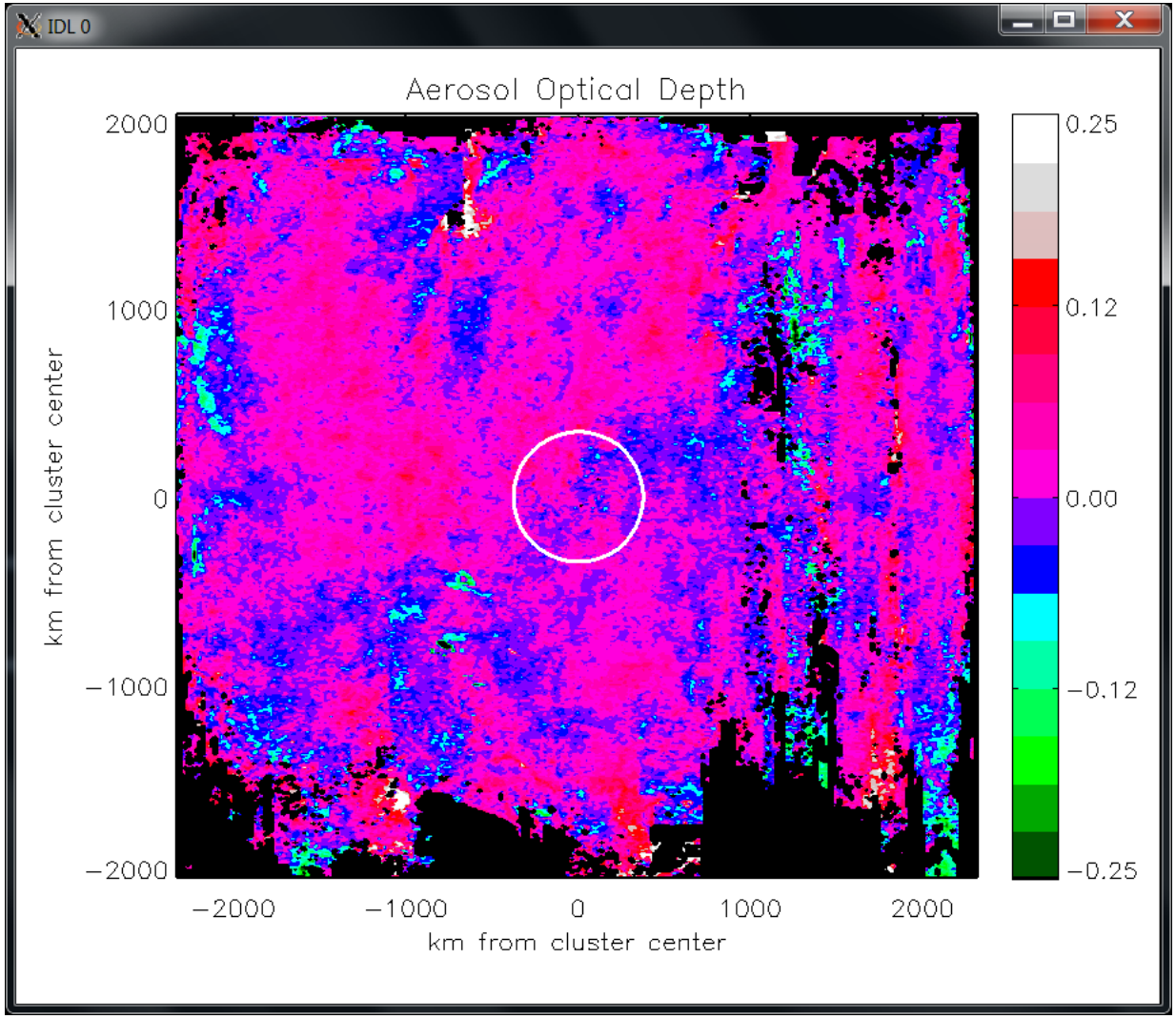
The NASA Hurricane Science Research (HSRP) Program, the NASA Energy and Water-cycle Study (NEWS) Program, and the AIRS project at JPL.

Show following instead of dissertation URL?

Coming soon:

Collimore, C. C., Eric Fetzer, Rob Fovell, 2019: The Effect of High Aerosol Concentrations on Tropical Cyclone Formation**?**, *Mon. Wea. Rev*.**?**

- Very first slide:
- Say, “The question is: do anomalously high aerosol concentrations in a region affect the formation of tropical cyclones in that region?”



MODIS parameter: optical_depth_small_best_ocean. AOD for fine mode particles only, using .55 microns wavelength.

The effect of RH on AOD

AOD is a function of:

1. Number of aerosols
2. Size of aerosols
3. Scattering coefficient of aerosols

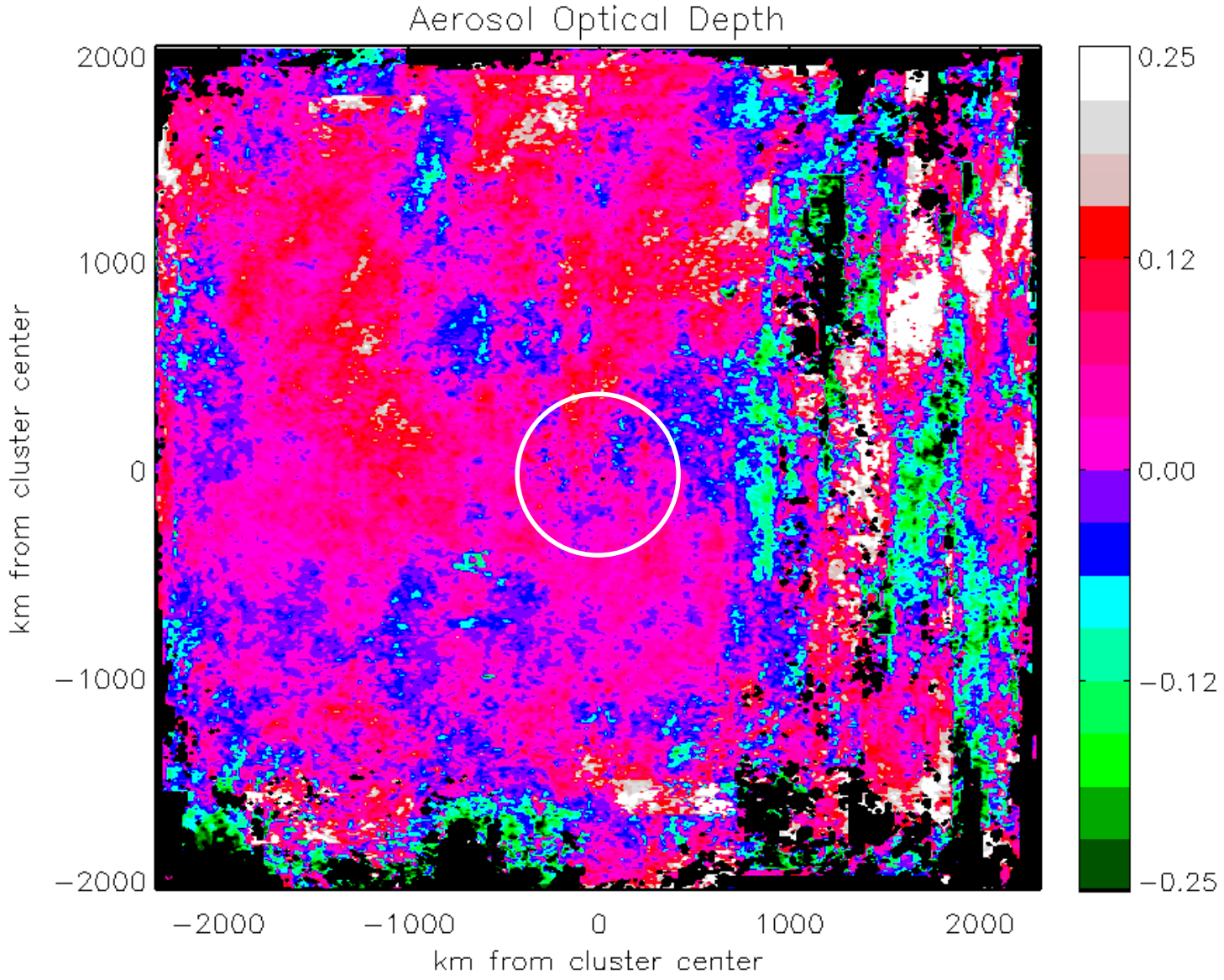
The effect of RH on AOD

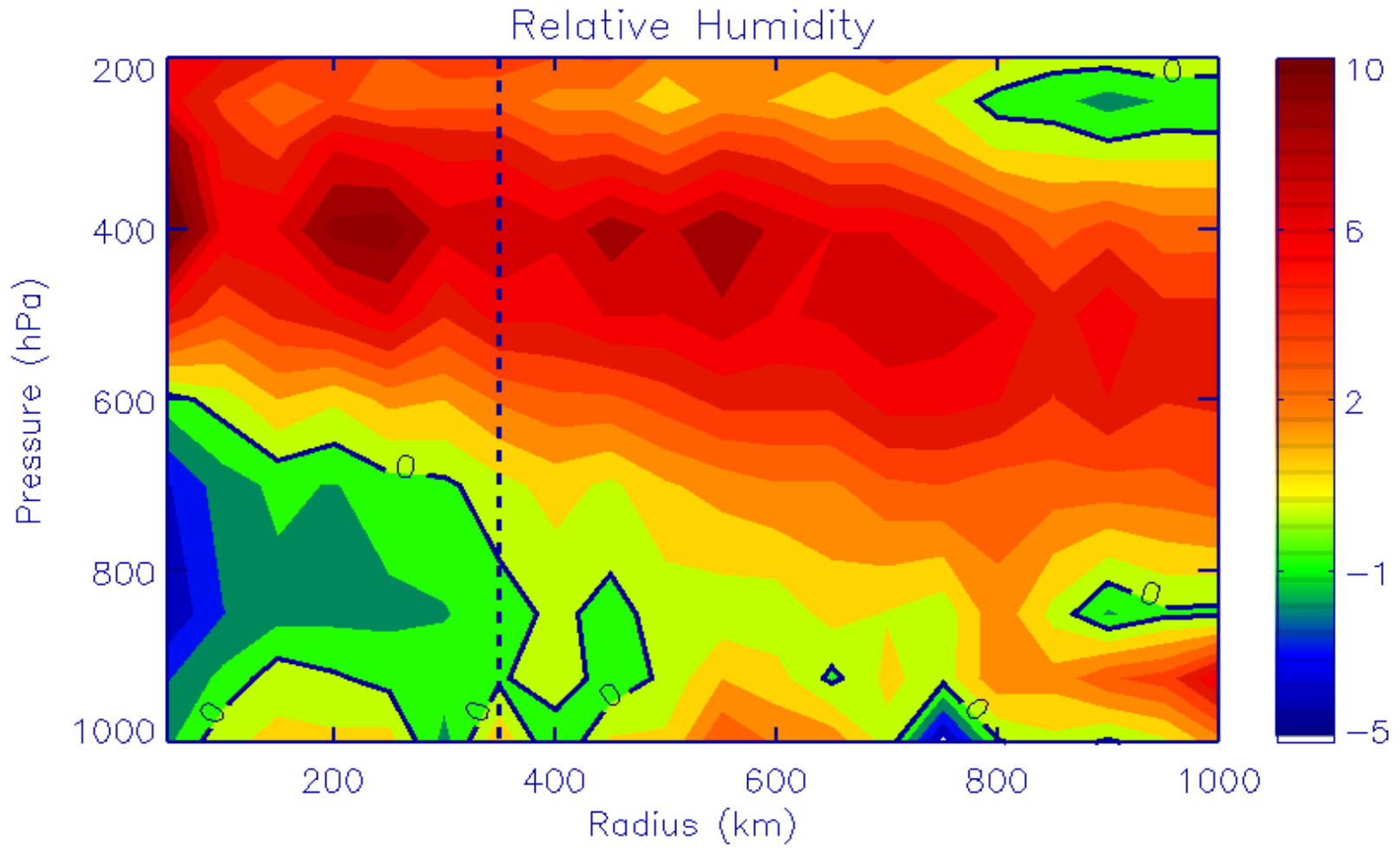
AOD is a function of:

1. Number of aerosols
2. **Size of aerosols**
3. **Scattering coefficient of aerosols**

Water vapor condenses on many aerosols, increasing their size and scattering coefficient.

Higher RH ⟶ Larger AOD


Aerosol Optical Depth
2000
1000
0
−1000
−2000
km from cluster center
−2000
−1000
0
1000
2000
km from cluster center
0.25
0.12
0.00
−0.12
−0.25

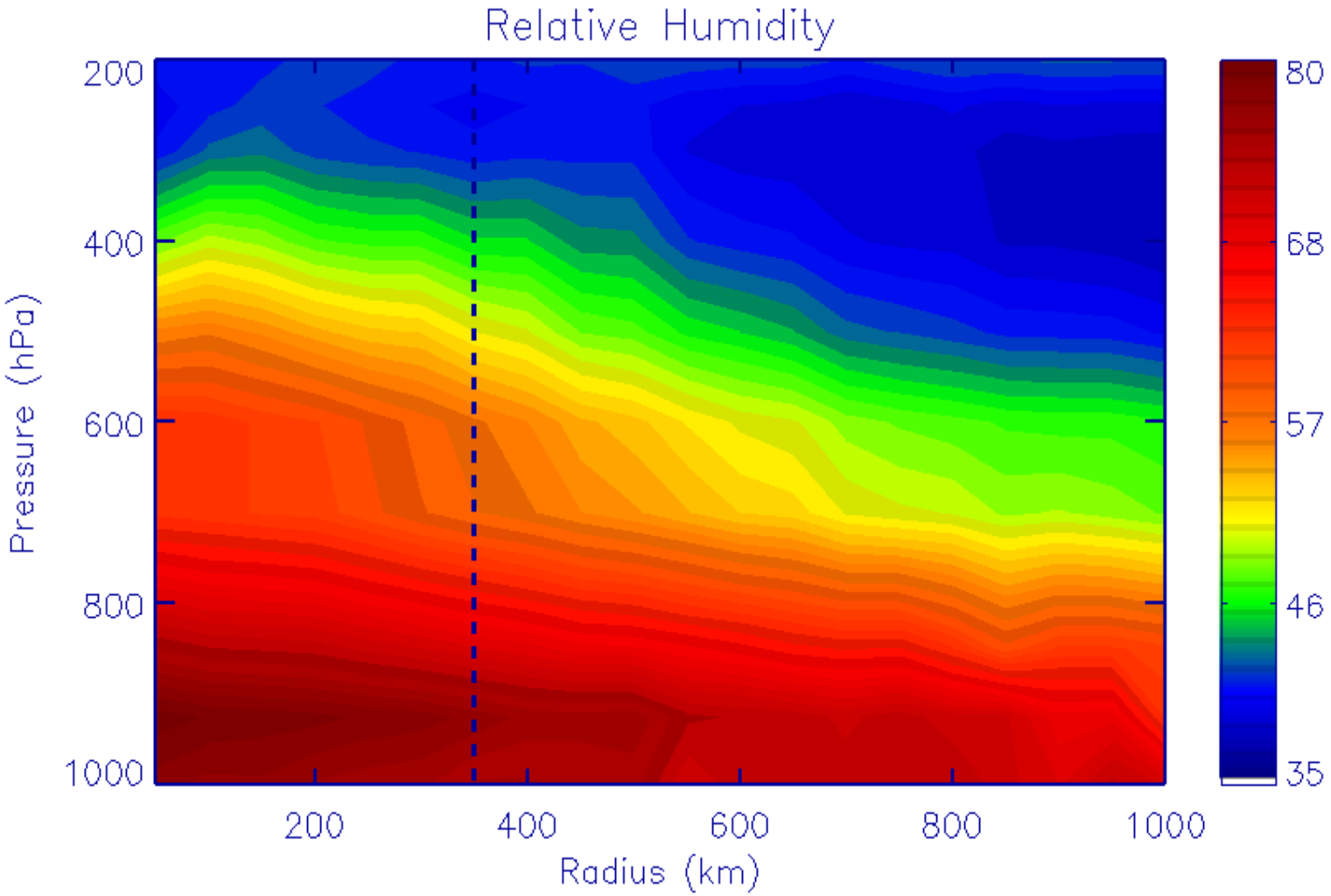

Relative Humidity
Pressure (hPa)
200
400
600
800
1000
200
400
600
800
1000
Radius (km)
10
6
2
−1
−5
0

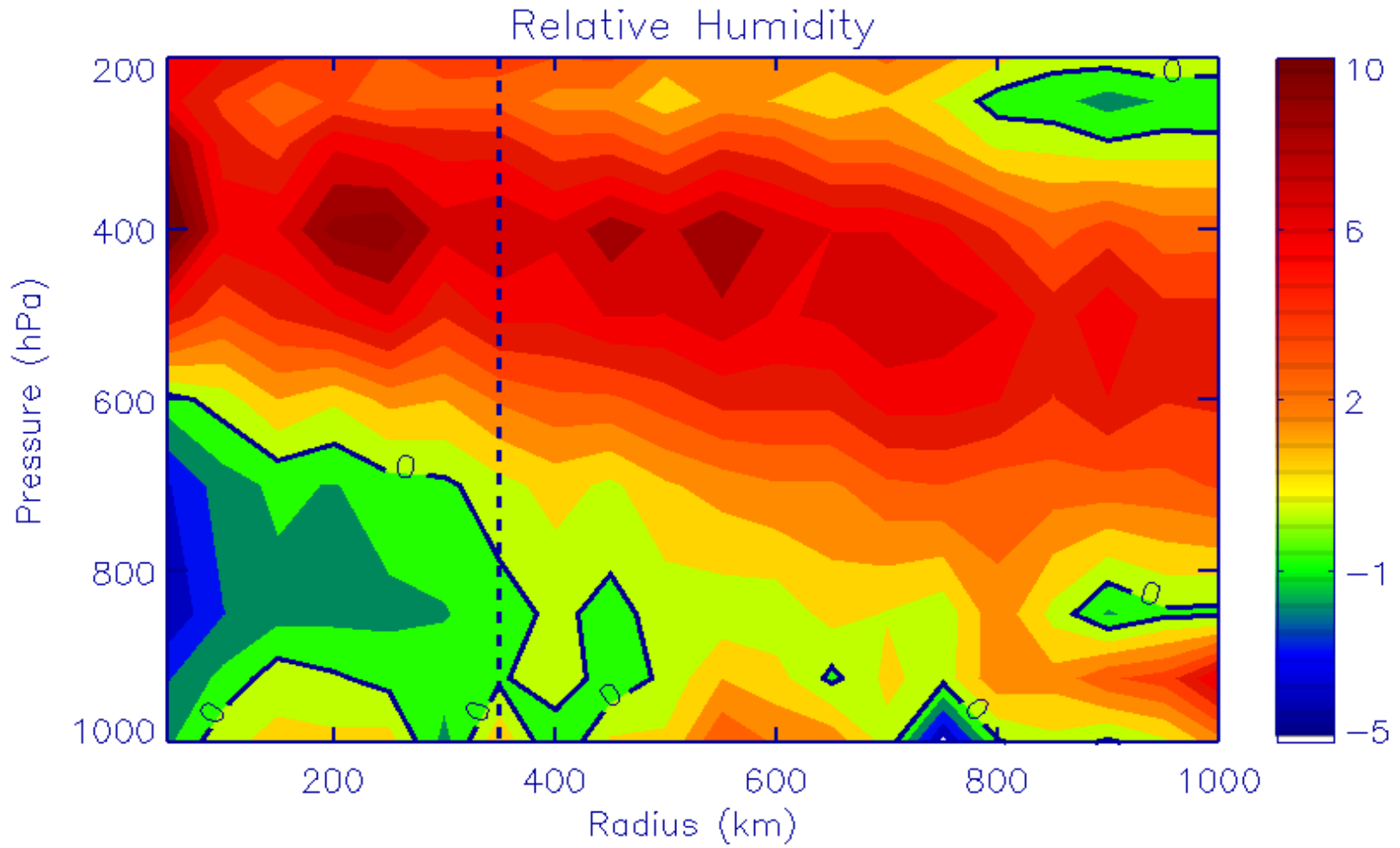
Aerosol Optical Depth In Clusters and the Nearby Environment (unitless)

Developers	Nondevelopers
.249	.197
.282	.183

Developers – 24% higher

Developers – 54% higher


Relative Humidity
200
400
600
800
1000
Pressure (hPa)
200
400
600
800
1000
Radius (km)
80
68
57
46
35


Relative Humidity
Pressure (hPa)
200
400
600
800
1000
200
400
600
800
1000
Radius (km)
10
6
2
−1
−5
0

The effect of RH on AOD

We averaged AOD for:

Developers with environmental RH < 44%

Nondevelopers with environmental RH > 44%

Aerosol Optical Depth In Clusters and the Nearby Environment (unitless)

Developers	Nondevelopers
.249	.197
.247	.208

Aerosol Optical Depth In Clusters and the Nearby Environment (unitless)

Developers	Nondevelopers
.249	.197
.247	.208

RH does not bias the AOD results