# Capturing the signals of shallow circulations in the trades

**Geet George | 10.11.2022**

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**MAX-PLANCK-INSTITUT**
FÜR METEOROLOGIE

# What is the mesoscale and why should we care?

## Meso-scale

*20-200 km;*

*environment varies over timescales of hours to a day*

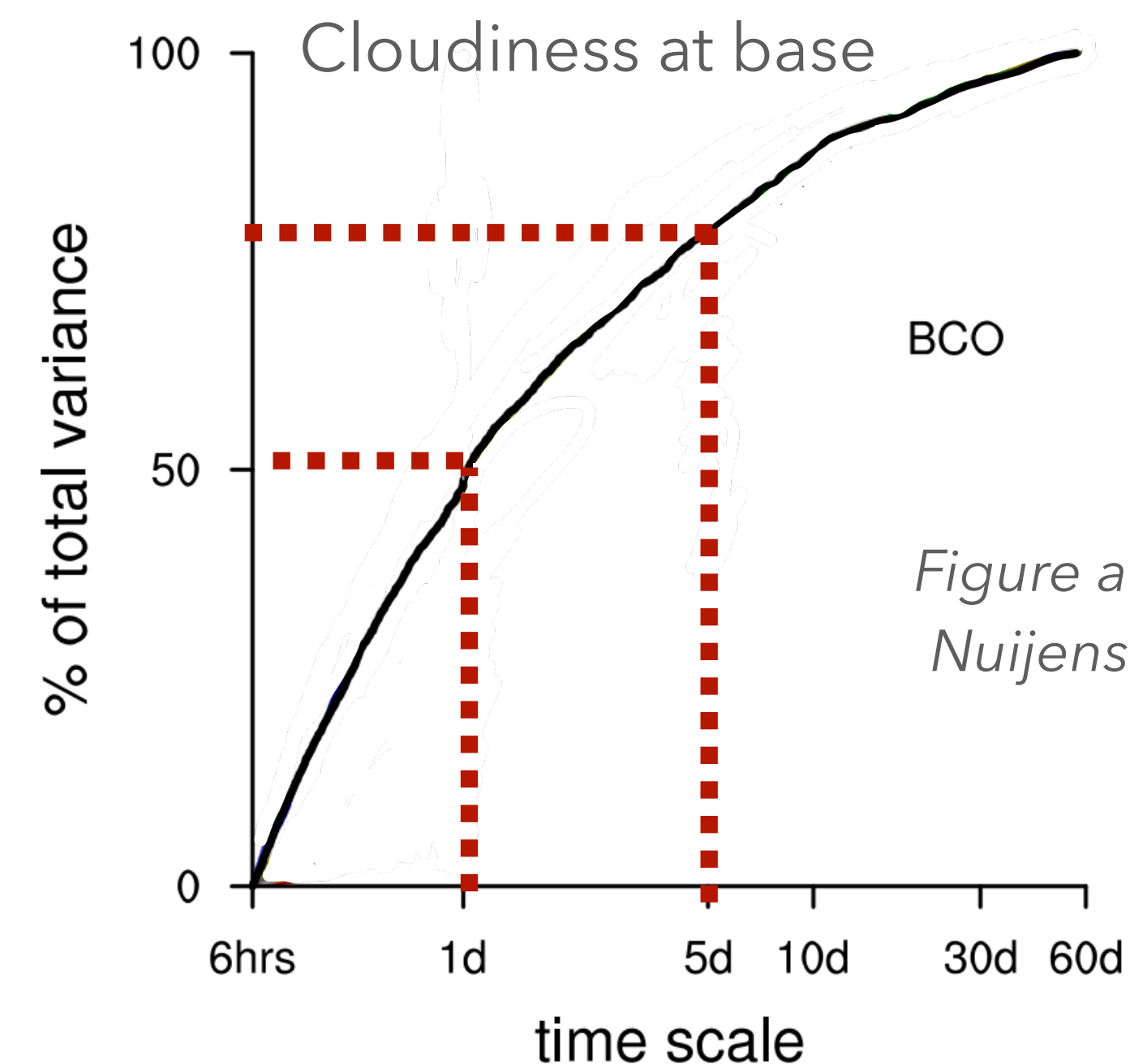- More than **50% & 75% of the variability** in low-level cloudiness less **than 1 and 5 days,** respectively.

Circulation, especially in the lower levels, is important to cloudiness

*Mauger & Norris (2010); Myers and Norris (2013)*
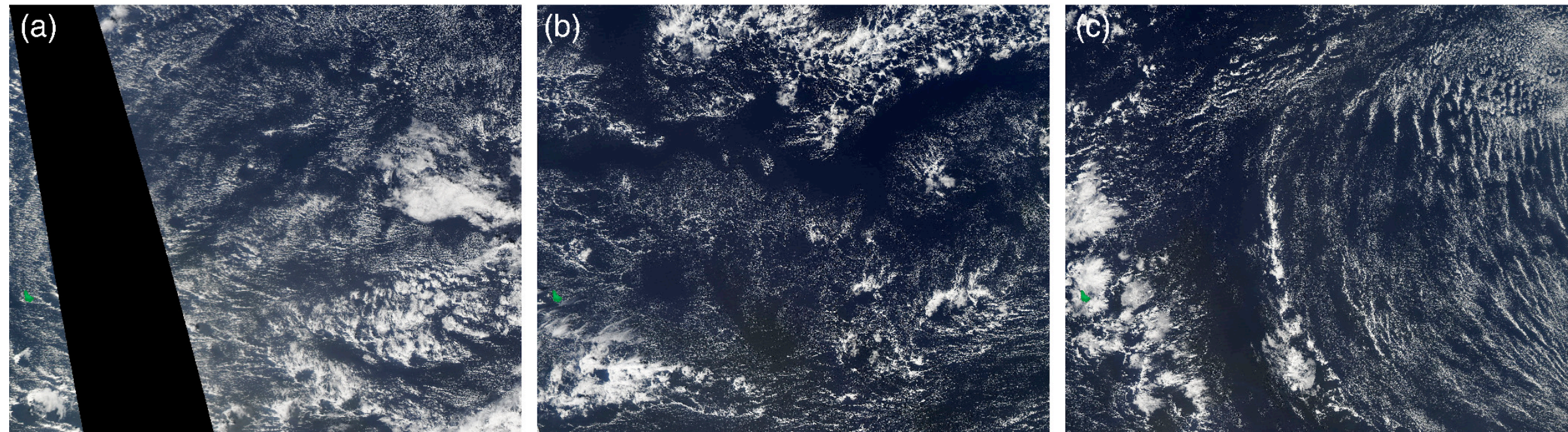*de Szoeke et al (2016); Stevens and Brenguier (2009)*

## Large-scale

*$\mathcal{O}$(1000 km)*

*varies over timescales of ~5 days to a month*



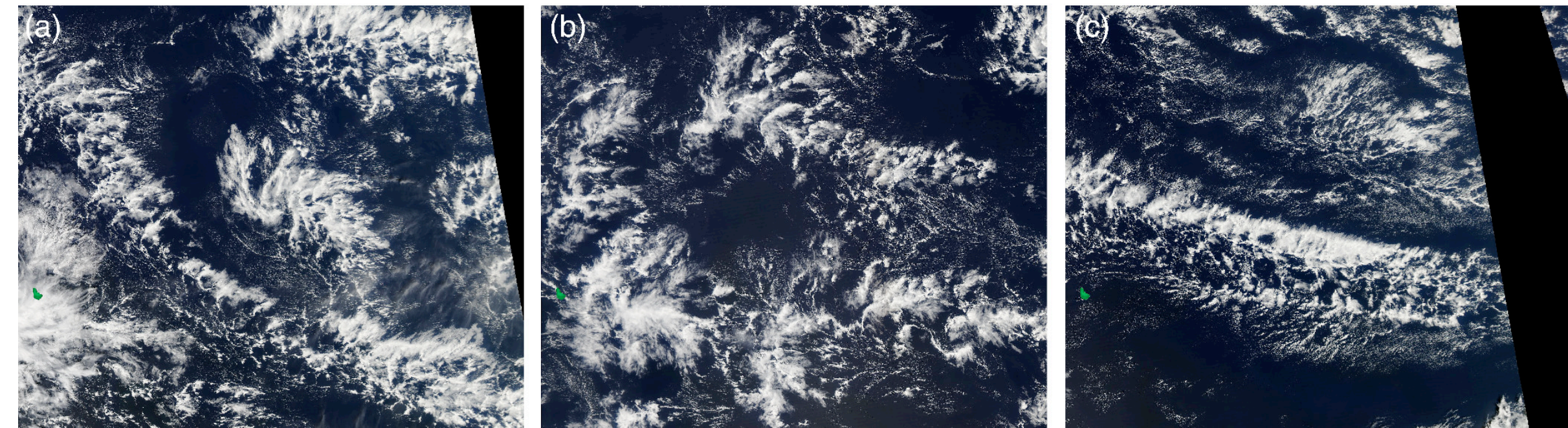*Figure adapted from Nuijens et al (2015)*

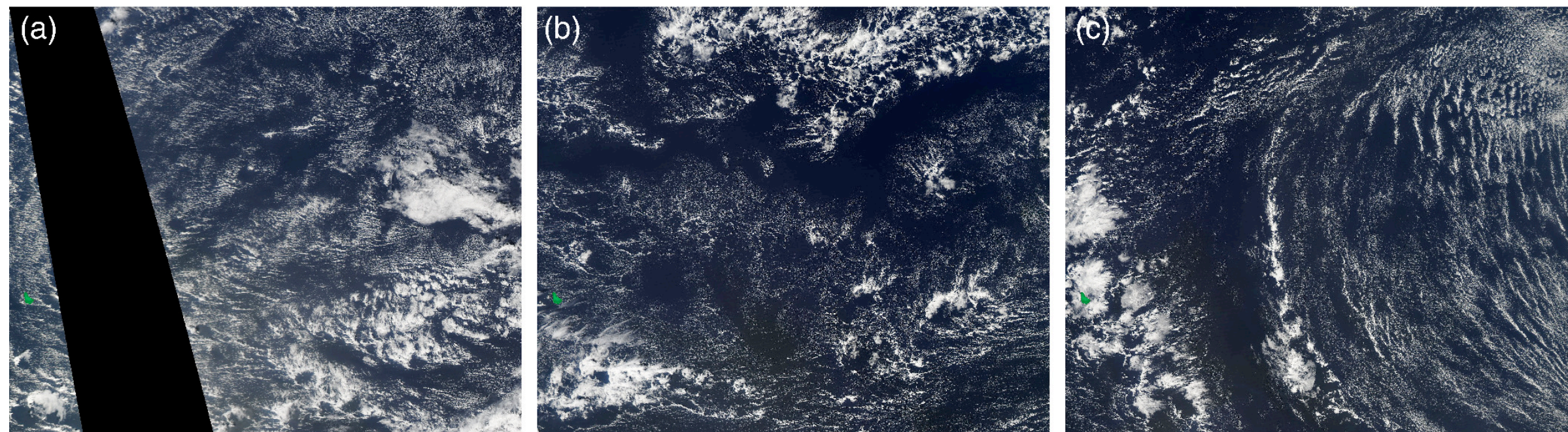# Spatial patterns of cloudiness

## Sugar



## Fish
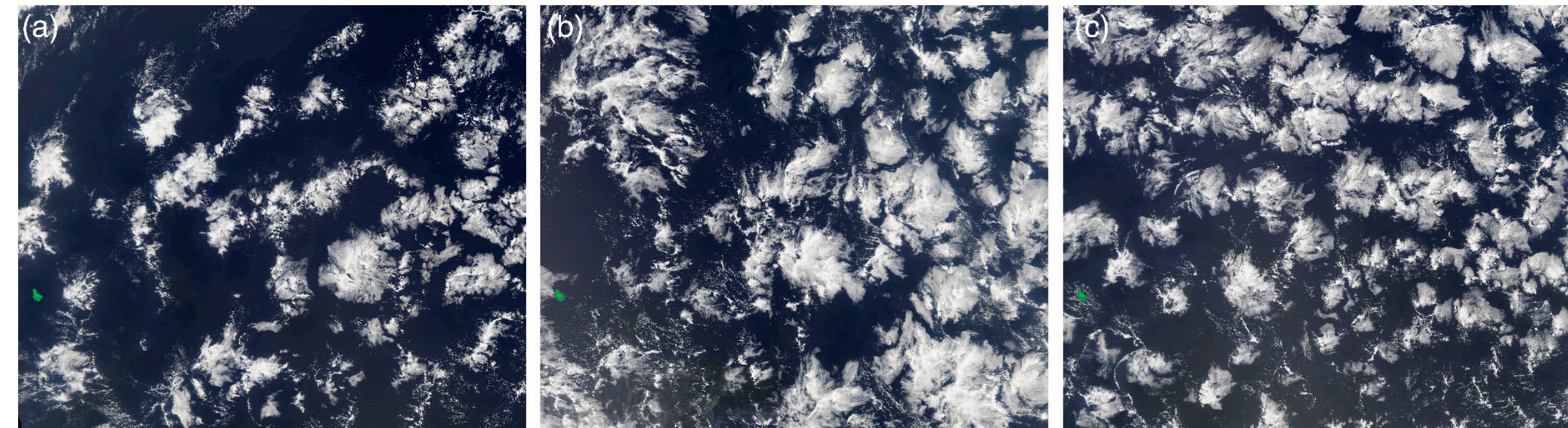


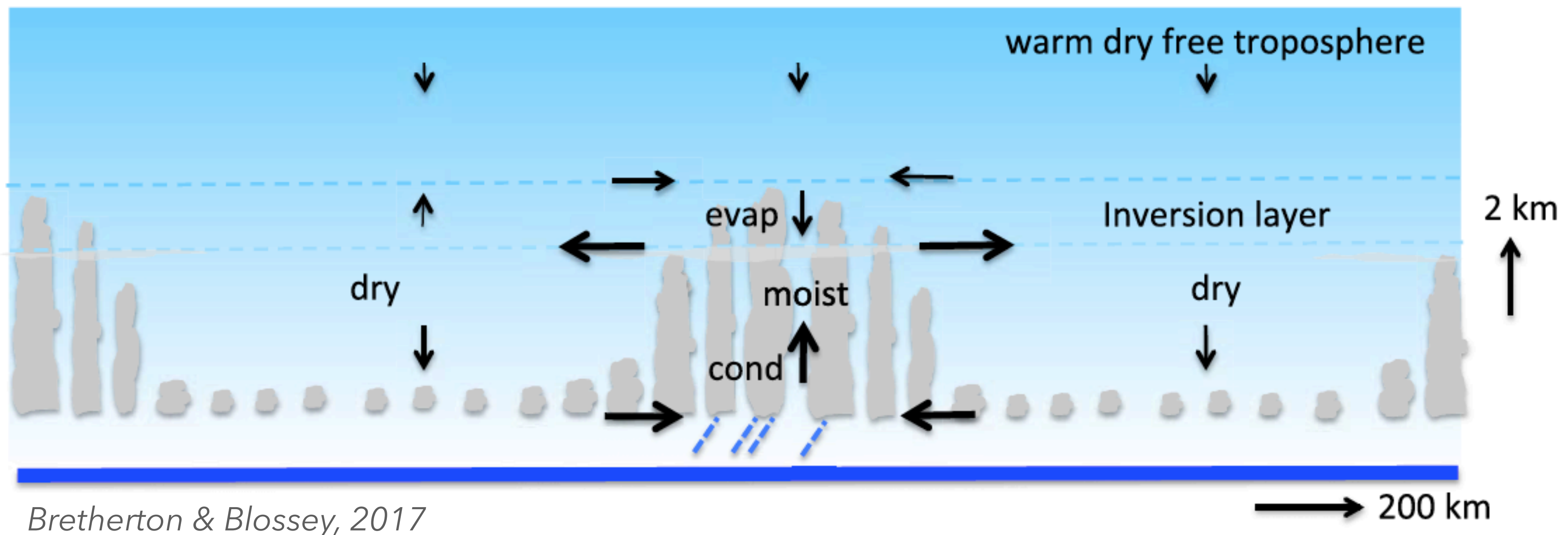## Gravel



## Flowers



*Figure adapted from Stevens et al (2019)*

# Shallow circulations in LES models

## Trigger and maintain convective organization

- Shallow circulations create and amplify moisture variance at mesoscales, thus facilitating convective aggregation.

*Bretherton & Blossey et al, 2017; Narenpitak et al, 2021; Janssens et al, (ongoing)*



*Bretherton & Blossey, 2017*

# Shallow circulations in LES models

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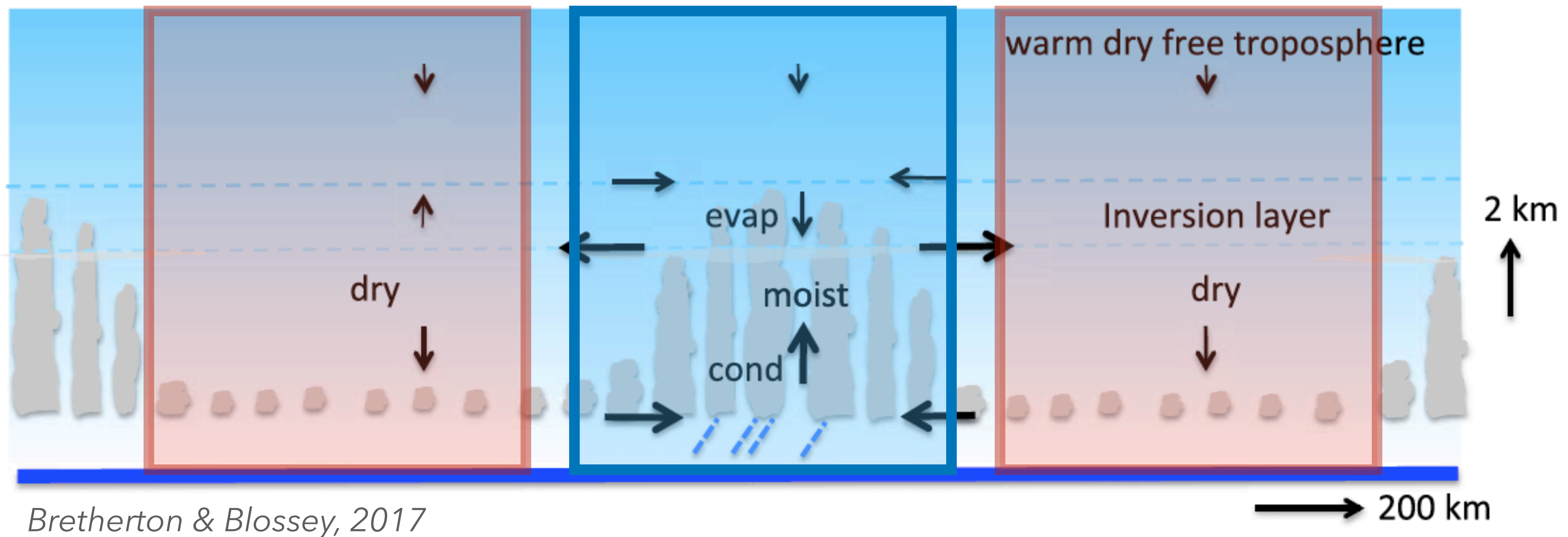*Bretherton & Blossey et al, 2017; Narenpitak et al, 2021; Janssens et al, (ongoing)*
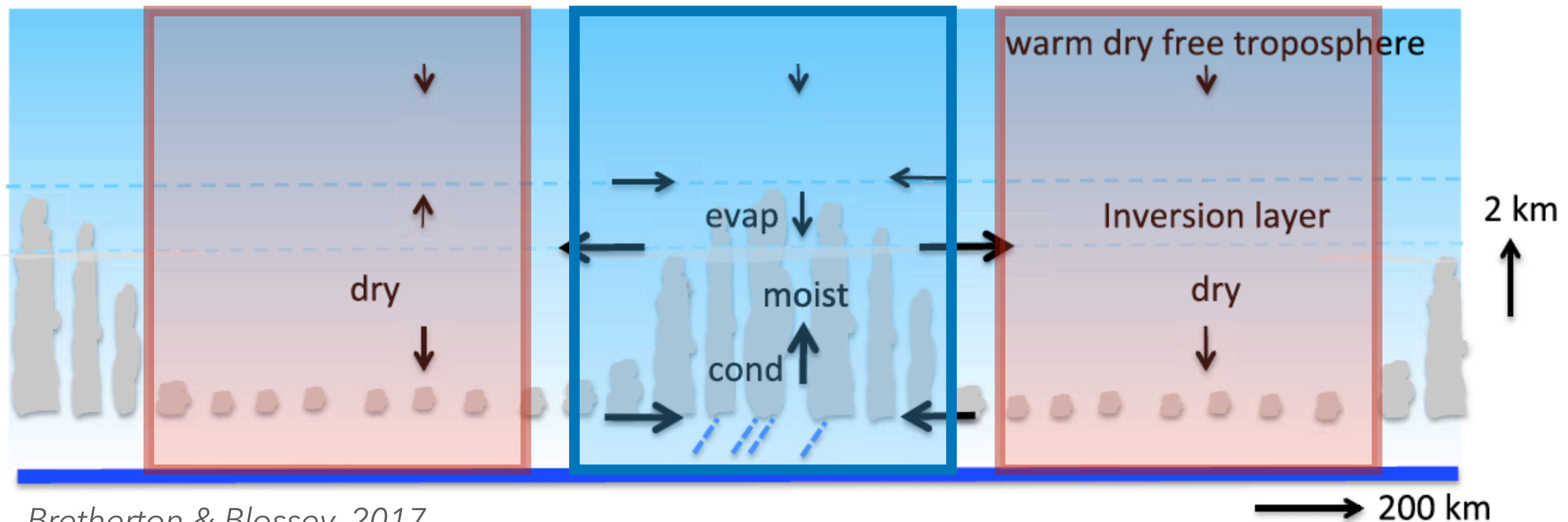


*Bretherton & Blossey, 2017*

# Shallow circulations in LES models

Trigger and maintain convective organization

⚠️ **No observations of mesoscale vertical motion!**
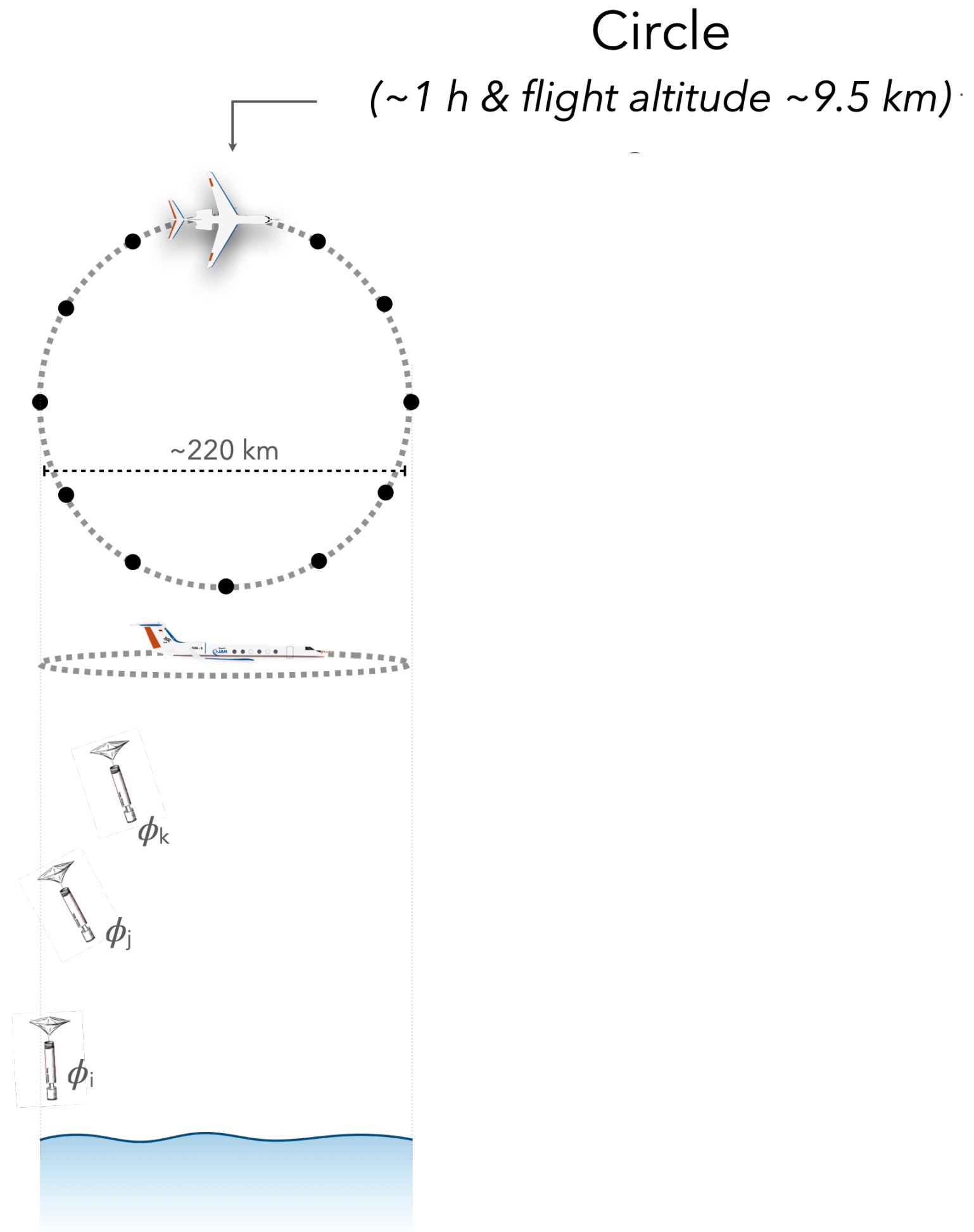


*Bretherton & Blossey, 2017*

warm dry free troposphere

Inversion layer

dry

moist

evap

cond

dry

2 km

200 km

# EUREC[4]A Measurements

Mesoscale divergence : area-averaged over 220 km diameter circle

Circle

*(~1 h & flight altitude ~9.5 km)*

~220 km

$$D = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}$$

Divergence

Subsidence
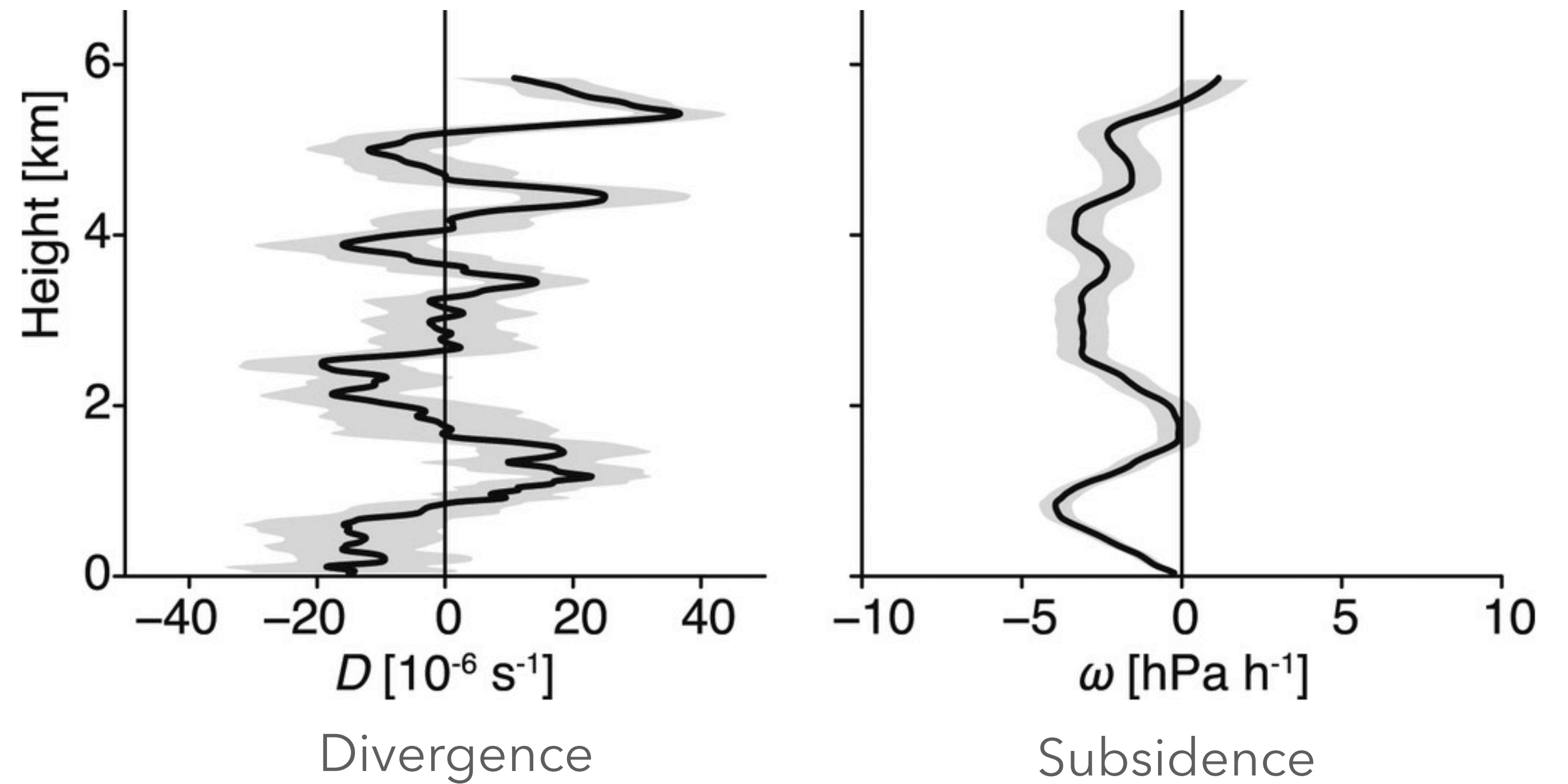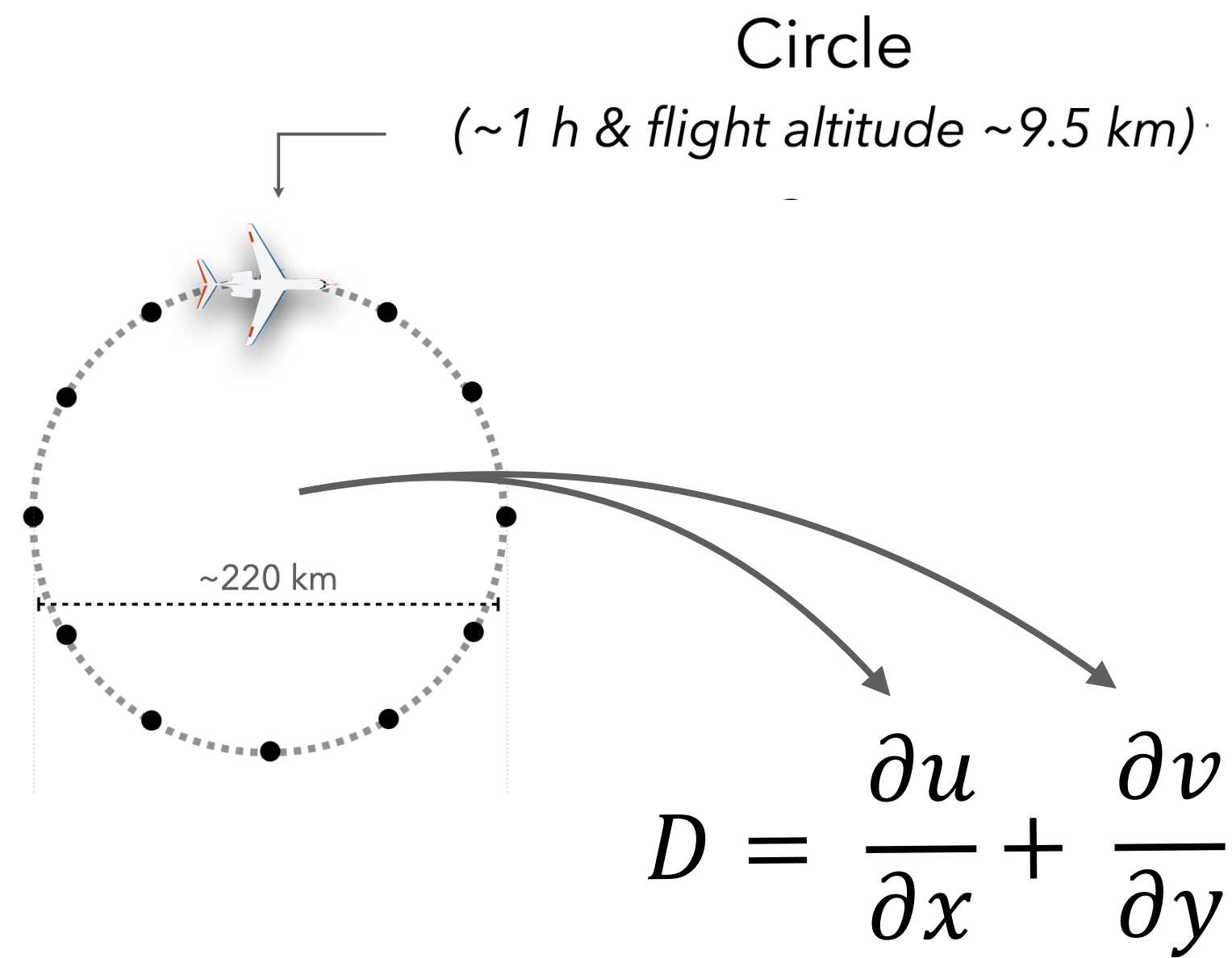
*Bony & Stevens, 2019*

# EUREC[4]A Measurements

Mesoscale divergence : area-averaged over 220 km diameter circle

Circle
*(~1 h & flight altitude ~9.5 km)*

~220 km

$\phi_k$

$\phi_j$

$\phi_i$

# EUREC⁴A Measurements

## Mesoscale divergence : area-averaged over 220 km diameter circle



Circle
*(~1 h & flight altitude ~9.5 km)*

Circling Set
*(3 circles)*

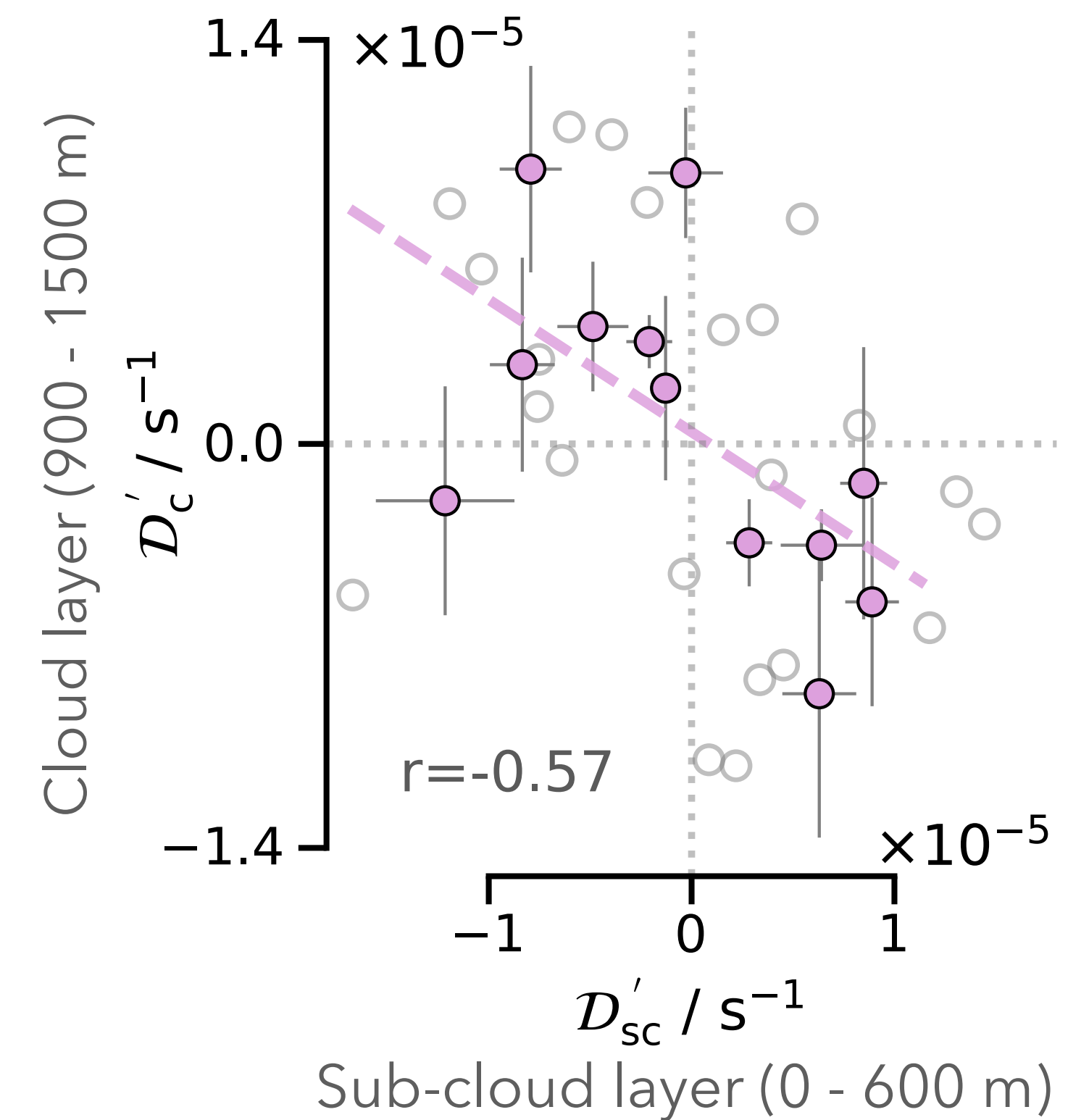Flight Day
*(2 circling sets separated by an hour)*
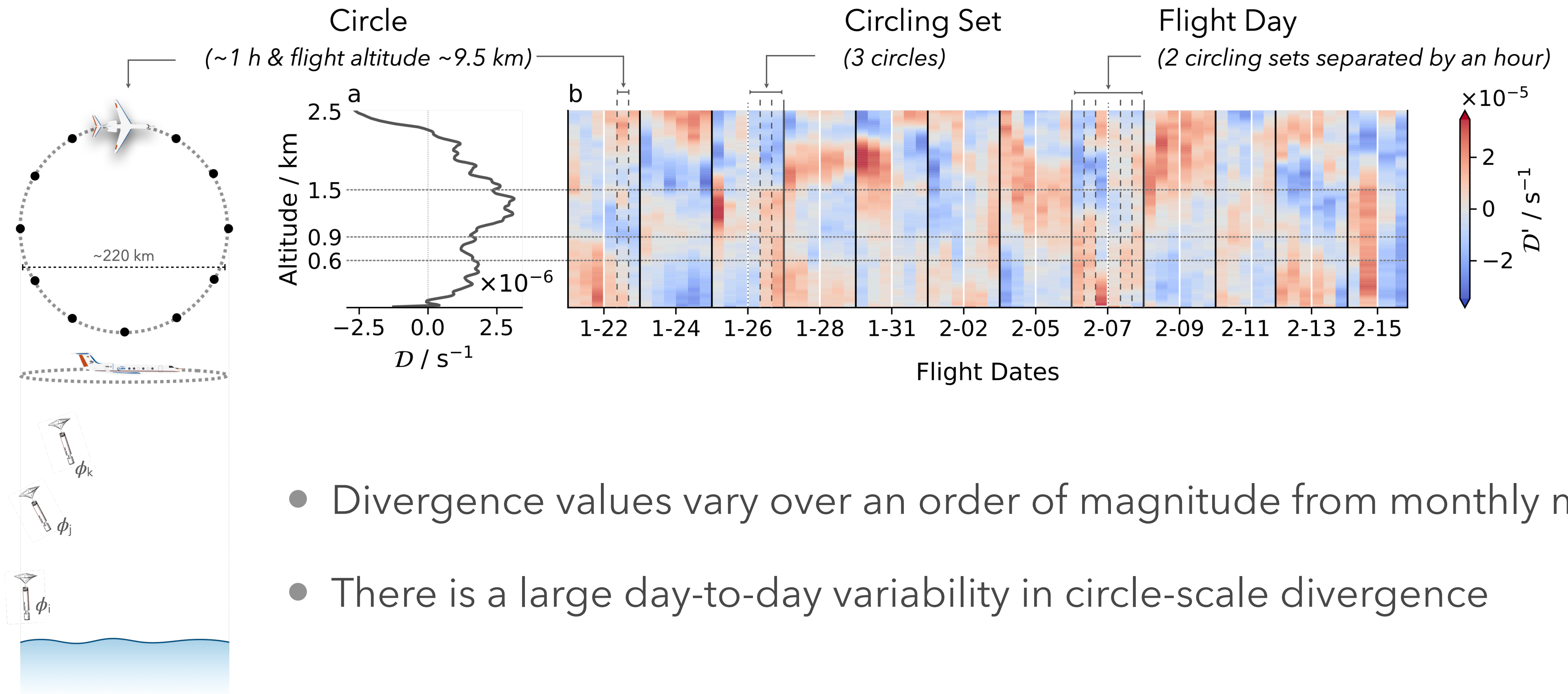
- Divergence values vary over an order of magnitude from monthly mean

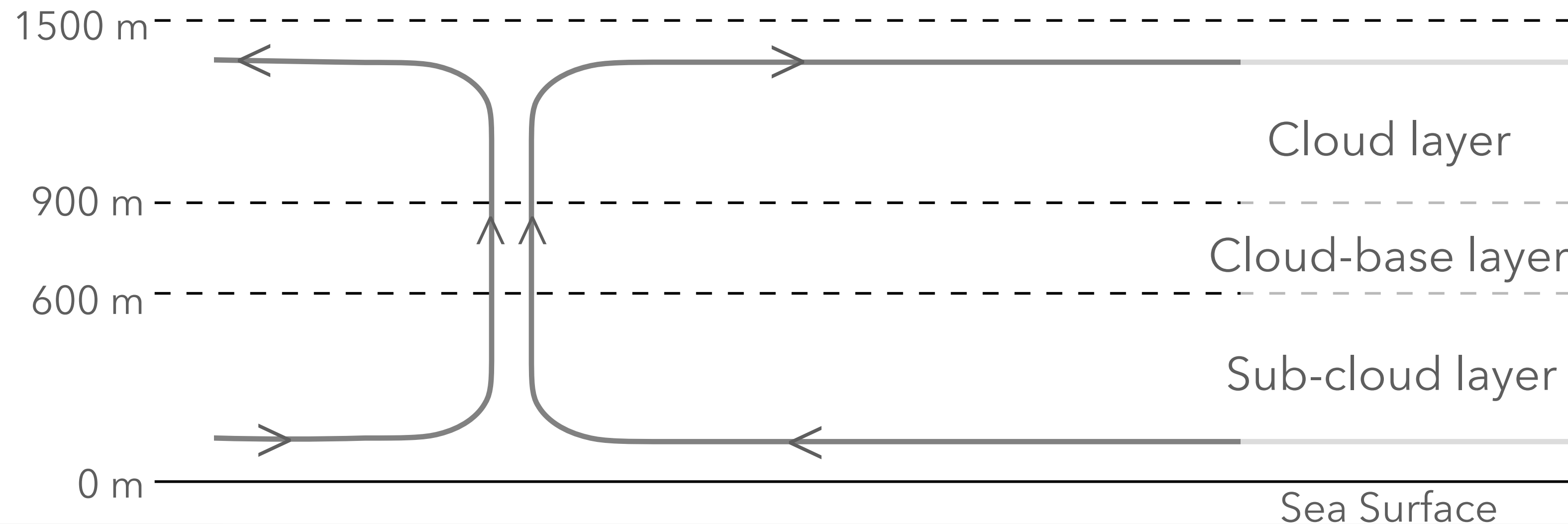- There is a large day-to-day variability in circle-scale divergence

# Discovering circulations in measurements

# Anti-correlation in divergence

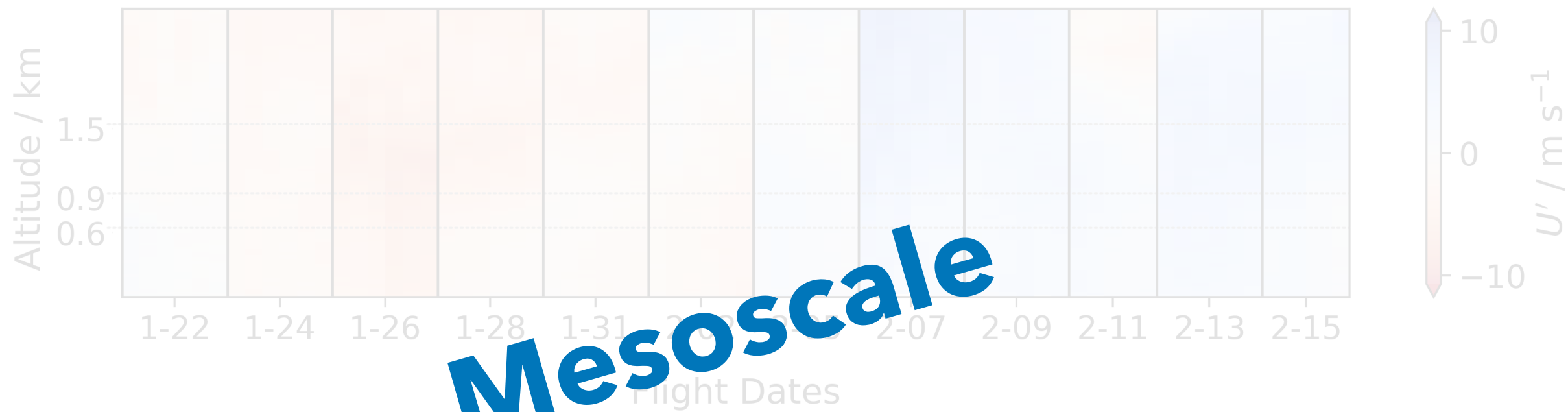○ Opposite signs of divergence in sub-cloud and cloud layers almost everyday
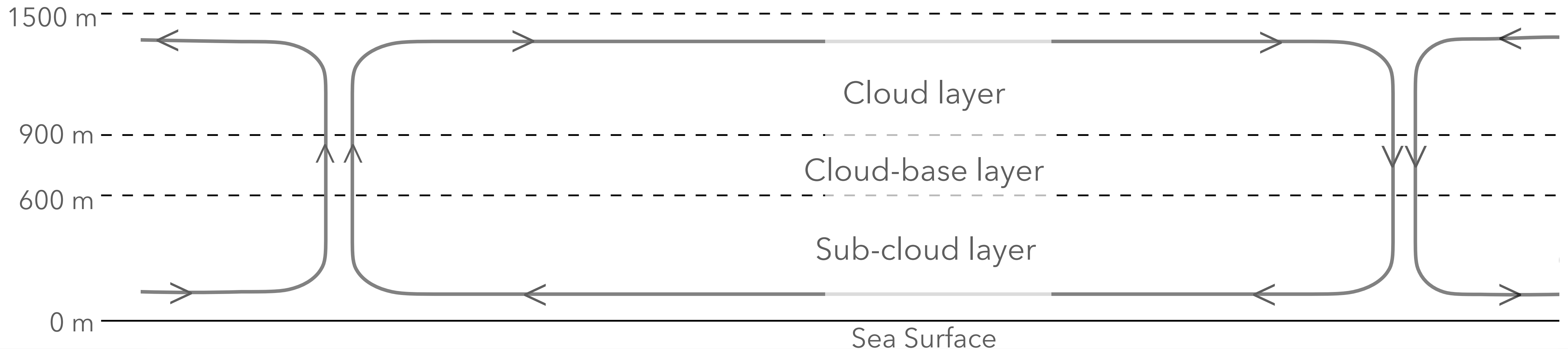
# Shallow Overturning Circulations?

# Are these mesoscale signals?

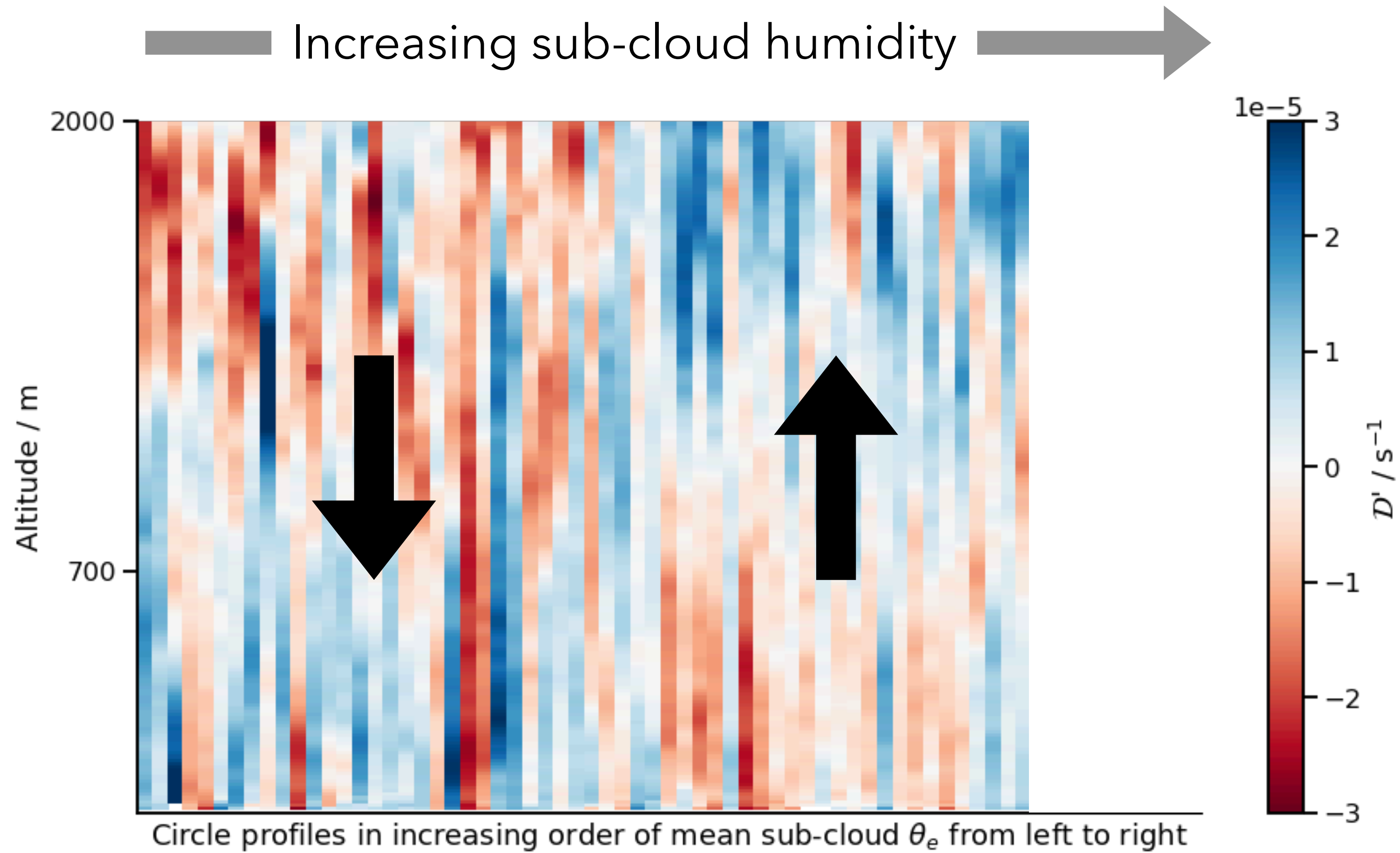Horizontal wind speed | *Synoptic scale variability*



**Mesoscale**

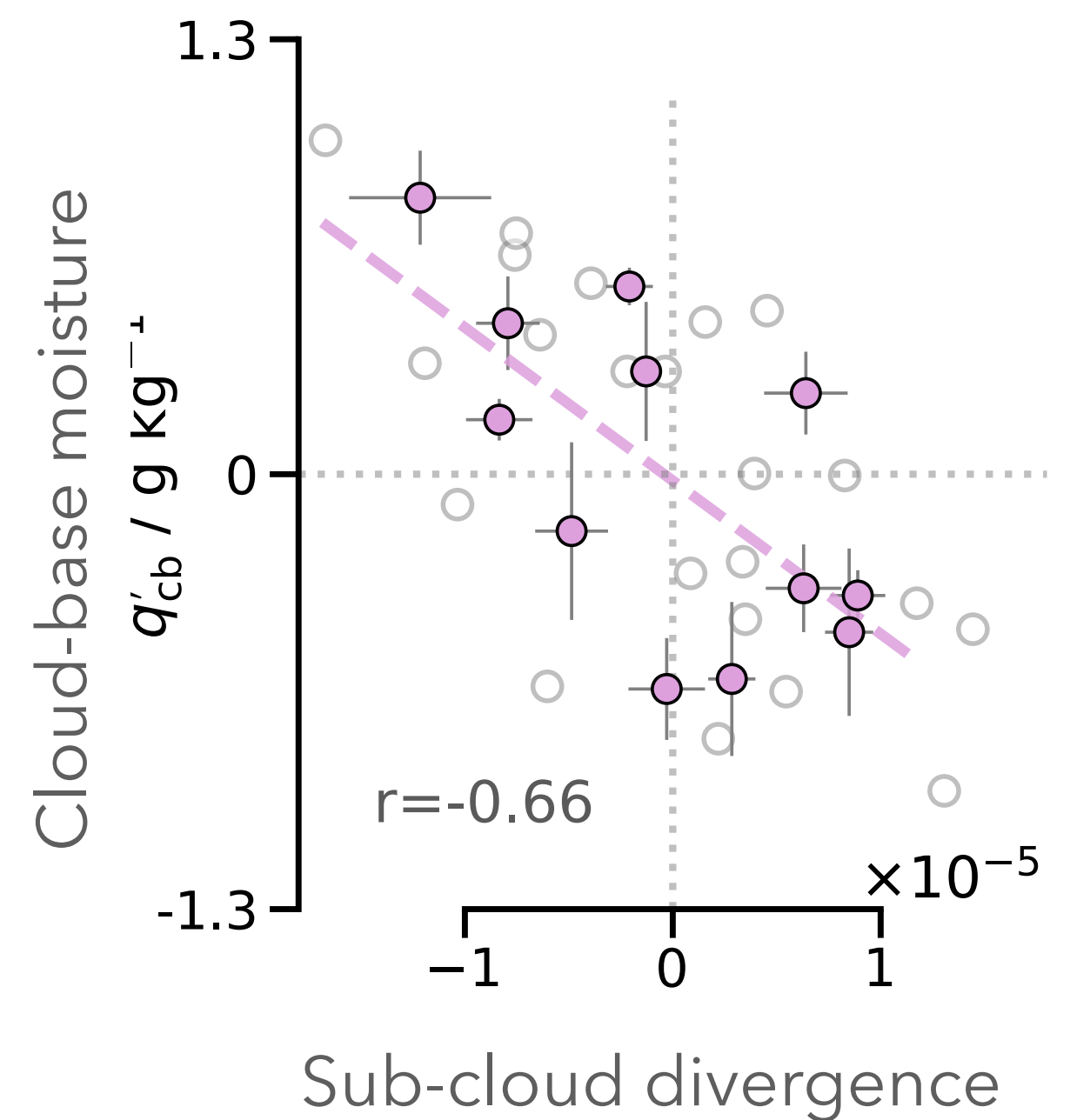## Shallow Overturning Circulations   (SMOCs)
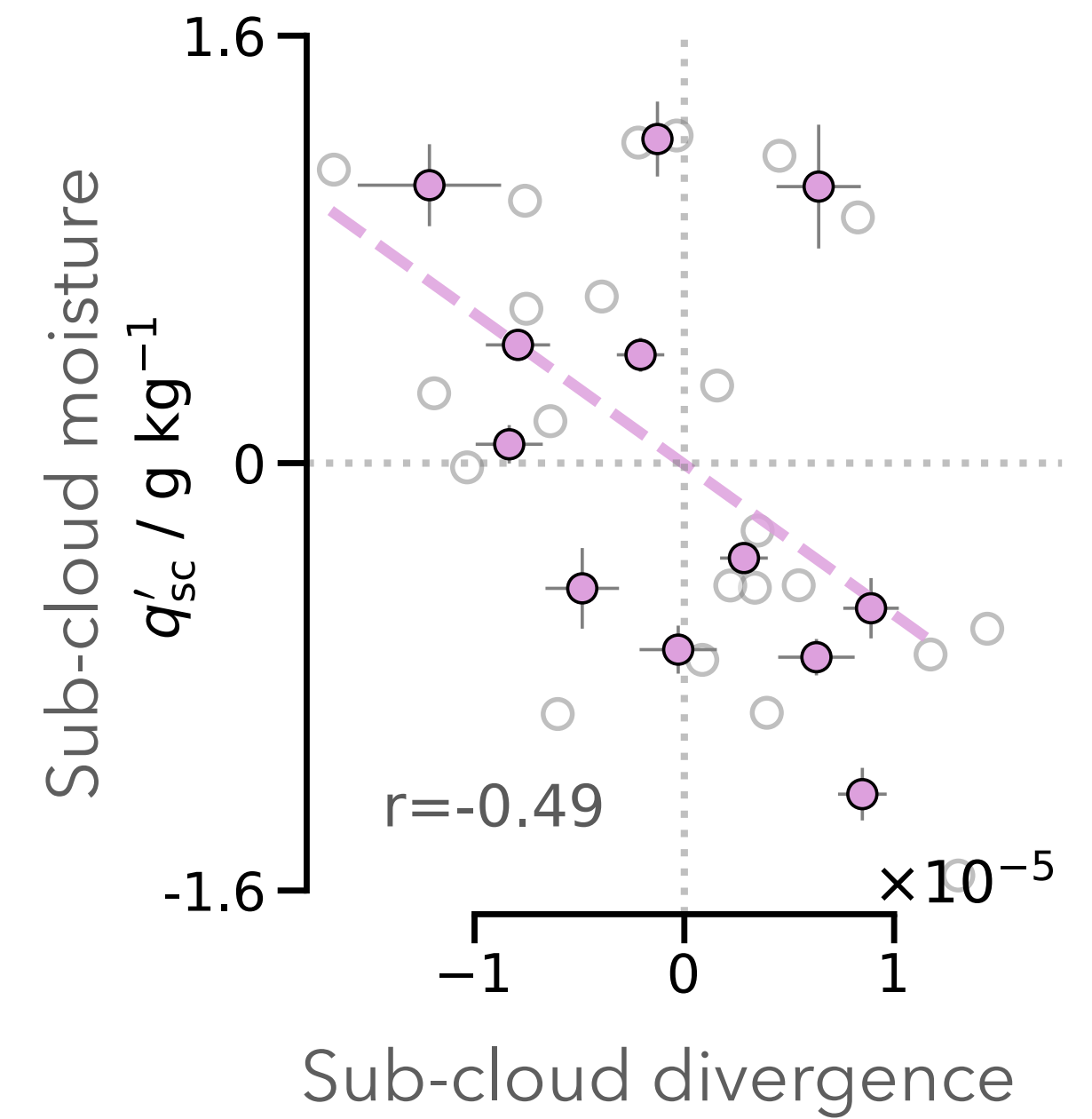
# SMOCs &
# moisture variance

# Cloud-base & sub-cloud moisture

## Vary with sub-cloud divergence



Increasing sub-cloud humidity

Altitude / m

2000

700

Circle profiles in increasing order of mean sub-cloud $\theta_e$ from left to right

$D'$ / $s^{-1}$

1e−5

Sub-cloud moisture $q'_{sc}$ / g kg$^{-1}$

1.6

0

−1.6

r=−0.49

Sub-cloud divergence

−1    0    1    ×10$^{-5}$

Cloud-base moisture $q'_{cb}$ / g kg$^{-1}$

1.3

0

−1.3

r=−0.66

Sub-cloud divergence

−1    0    1    ×10$^{-5}$

**Sub-cloud Convergence** ⟷ **Moister sub-cloud**

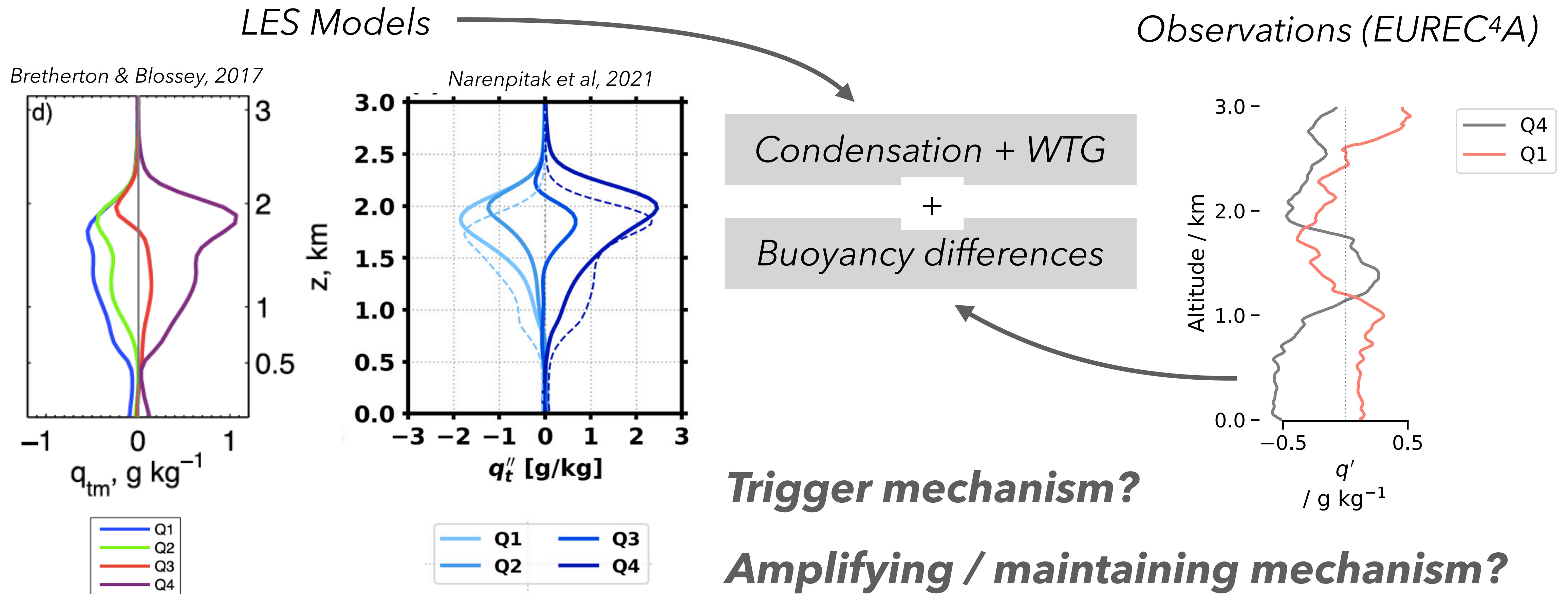# Circulation-moisture: Causal direction

r-value of q with sub-cloud D

- Time-lag correlation:
  Sub-cloud moisture responds over 2-3 h

- Sub-cloud divergence strongly
  influences sub-cloud moisture variance

Altitude / km

2

1

0

-0.5    0

0.0 h
1.5 h
3.0 h
$FD_{avg}$

$r_{min} = -0.67$
at 720 m

1500 m

Cloud layer

900 m

Cloud-base layer

$E$

600 m

$M' > 0$

Entrainment drying efficiency
reduced due to moist cloud base

Sub-cloud layer

Entrainment drying efficiency
increased due to dry cloud base

$E$

$M' < 0$

0 m

Sea Surface

# LES models show contrasting influence of SMOCs on moistening

- LES moisten / dry the cloud-top, as opposed to cloud-base in observations

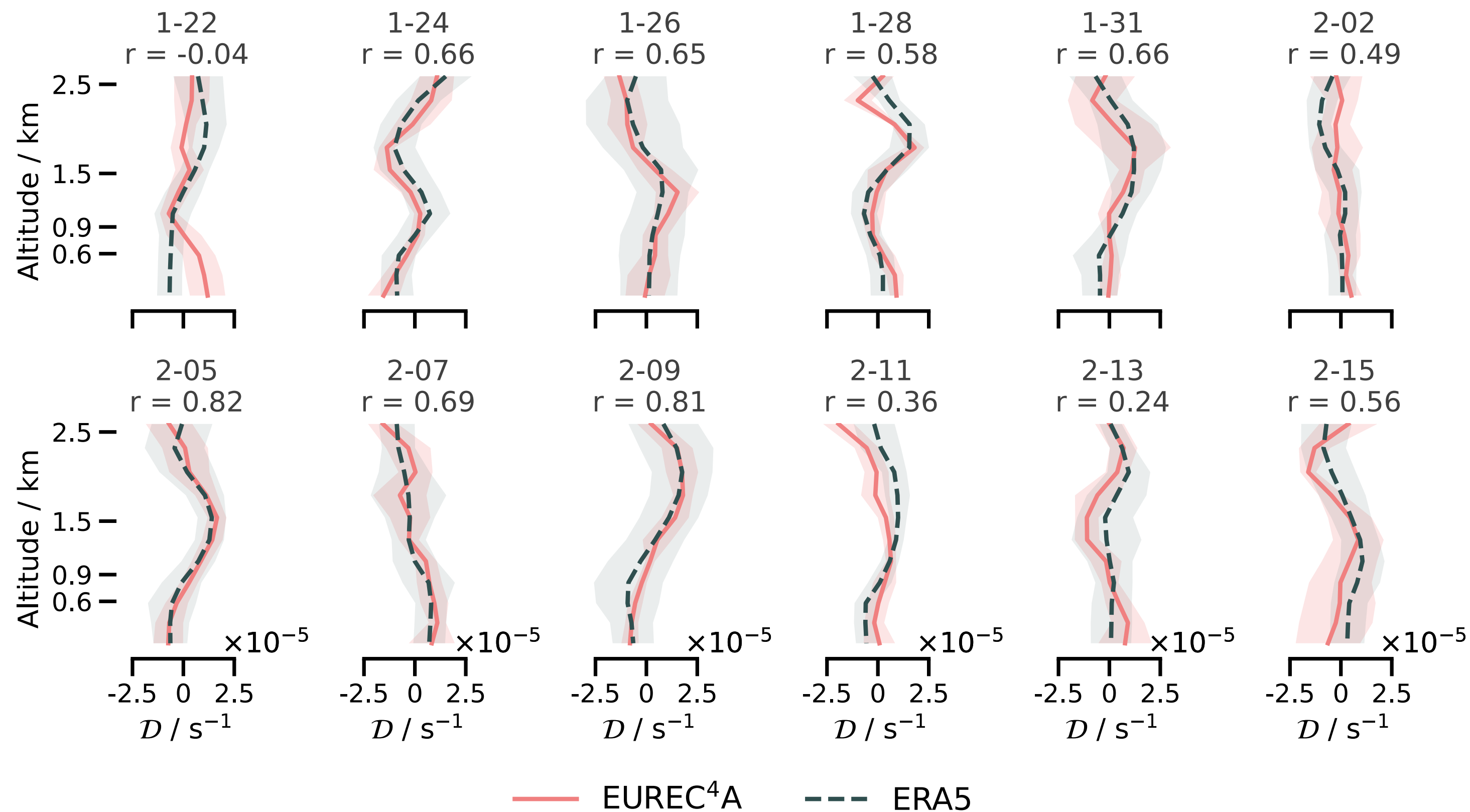- LES show almost no anomalies in the sub-cloud layer moisture

*LES Models*

*Observations (EUREC⁴A)*



*Bretherton & Blossey, 2017*

*Narenpitak et al, 2021*

Condensation + WTG
+
Buoyancy differences

**Trigger mechanism?**

**Amplifying / maintaining mechanism?**

# Scale of SMOCs

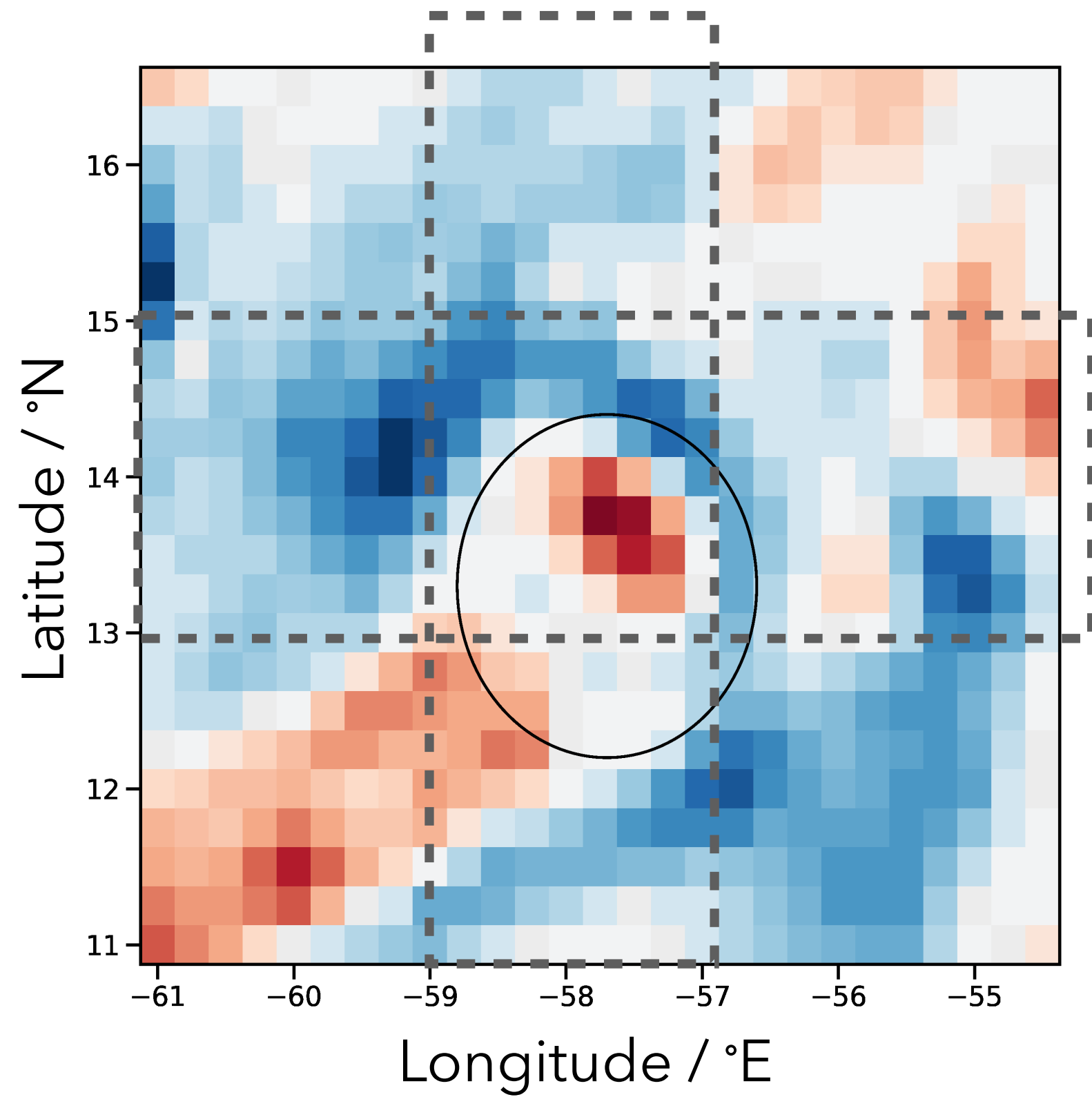# Looking at SMOCs in ERA5 reanalysis

But can we trust divergence from ERA5? Yes, we can...



- Comparison with EUREC[4]A divergence profiles

- ERA5 simulates divergence quite reliably

# Confirmation of SMOCs from ERA5



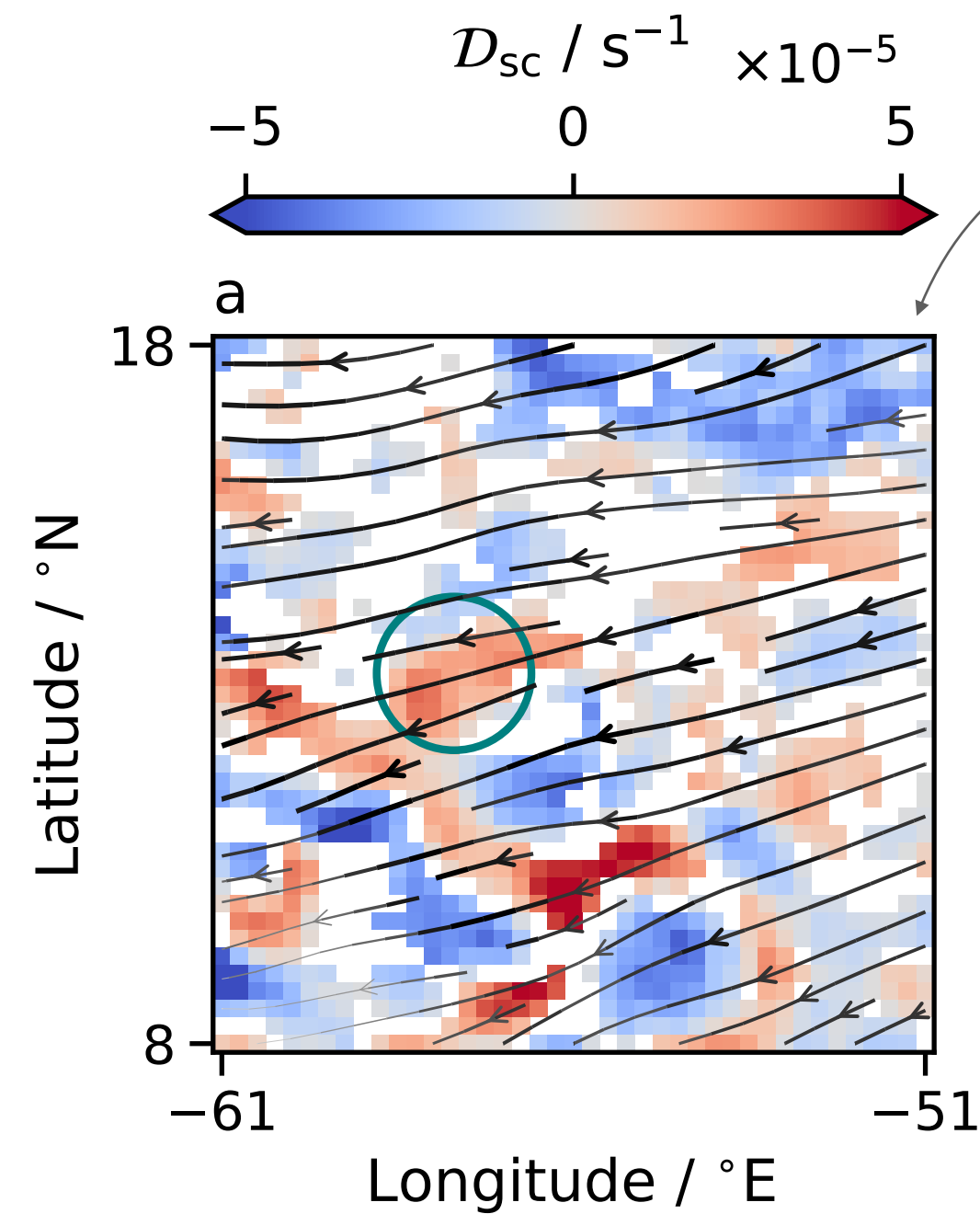Hourly from 26-01 10:00 UTC to 28-01-2020 12:00 UTC

**Sub-cloud mean divergence**
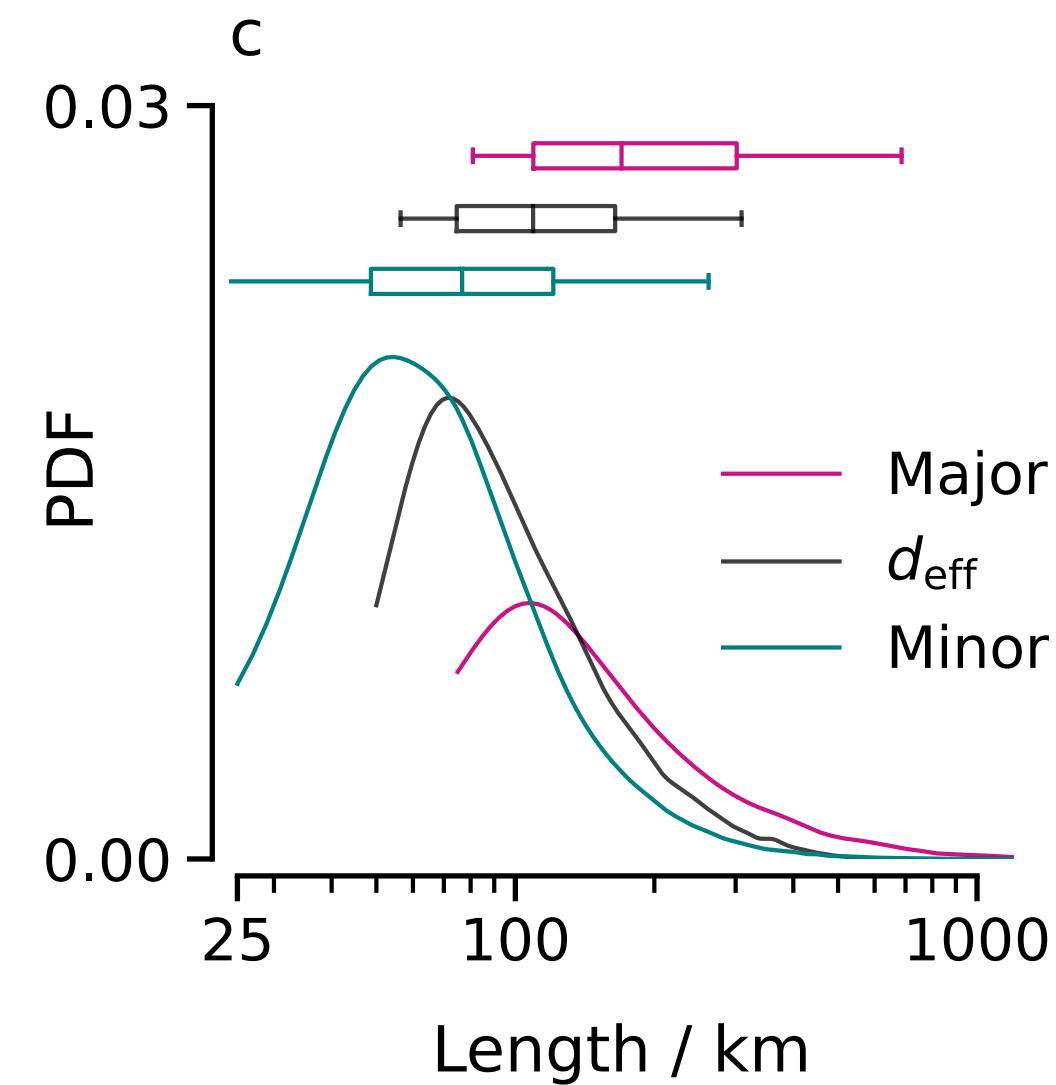Red (-ve): Convergence
Blue (+ve): Divergence

# Horizontal scale of SMOCs

Fitting objects from ERA5 into ellipses



Distribution during EUREC⁴A

Example



- Median values of SMOC objects: 100 - 200 km

- More elongated than circular objects

- Orientation of major axis mainly zonal; slight tendency to be along wind direction

# Inferring scale from EUREC⁴A circles

*Circulation with 200 km wide convergent & divergent branches (advecting ~9 m/s westwards)*
*Aspect ratio is to scale for the 1.5 km deep (line thickness), 400 km wide (line length) SMOC*

*EUREC⁴A sampling area (geographically fixed);*
*circle diameter shown to scale with respect to SMOC*

*Time (7 h)*
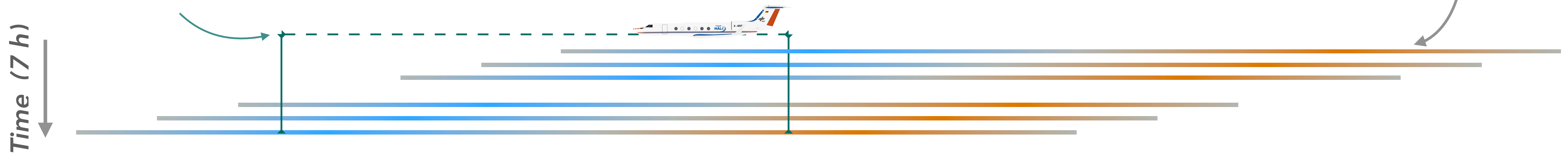
**The consistency in EUREC⁴A measurements over a single day makes sense with such scales**

# How frequently do they occur?

ERA5 sub-cloud divergence every 12 hours during EUREC⁴A…
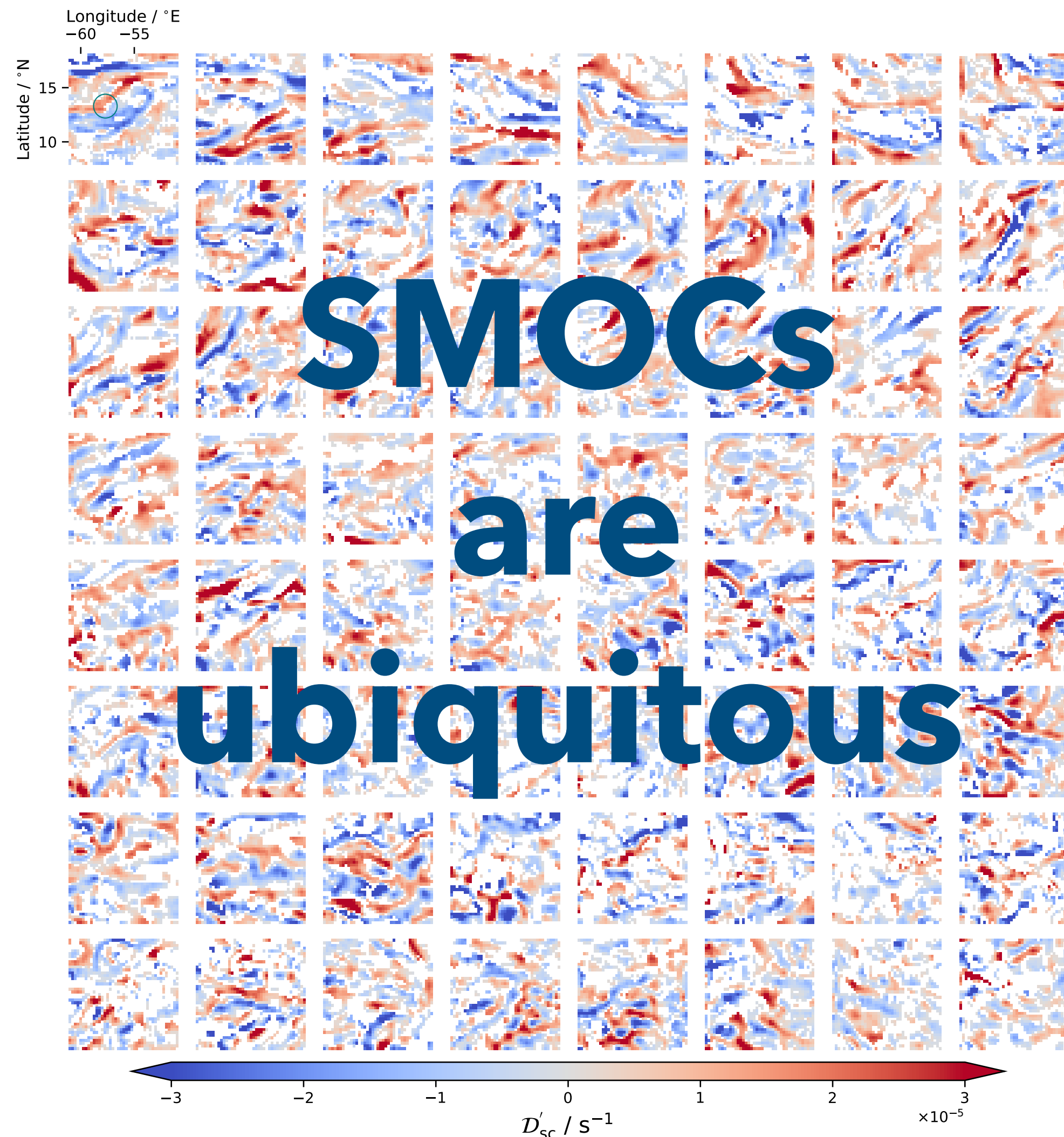


Colours only where opposite signs in the sub-cloud and cloud layers

**SMOCs cover 45% area, 95% of the time**