Self-aggregation of convection in a GCM run in Radiative Convective Equilibrium (RCE)

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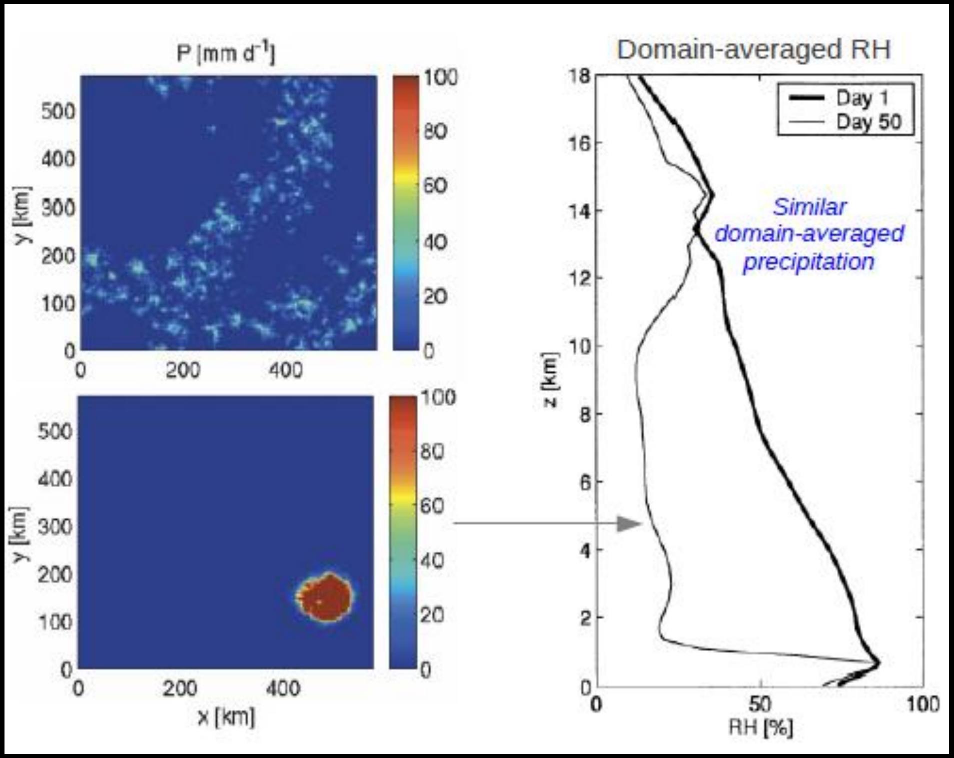
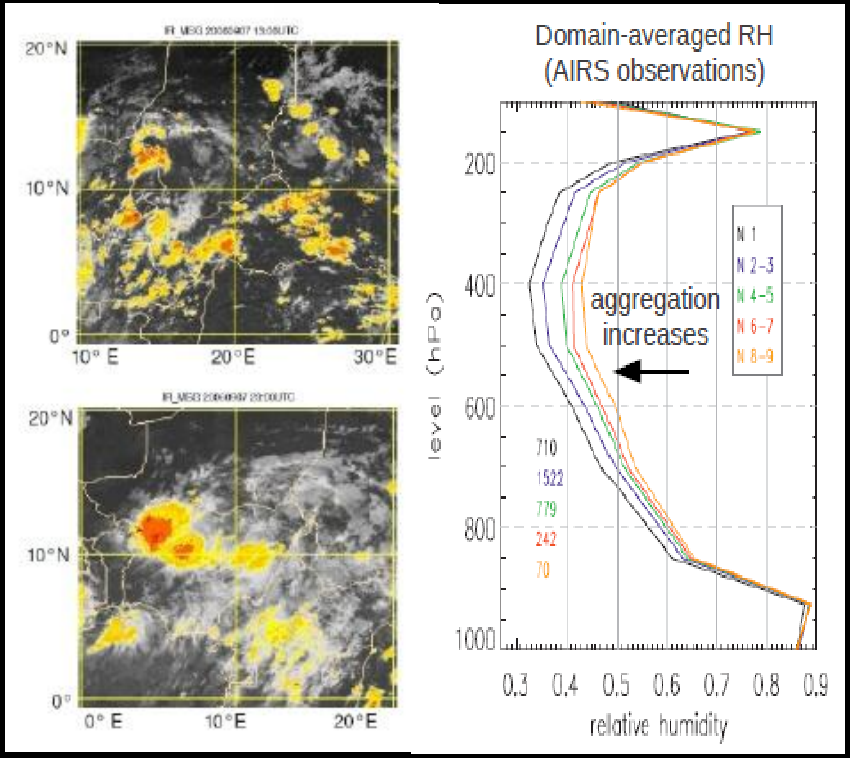
Effect on the mean state of the atmosphere

Influence on the large-scale atmospheric state

Cloud Resolving Models



Observations

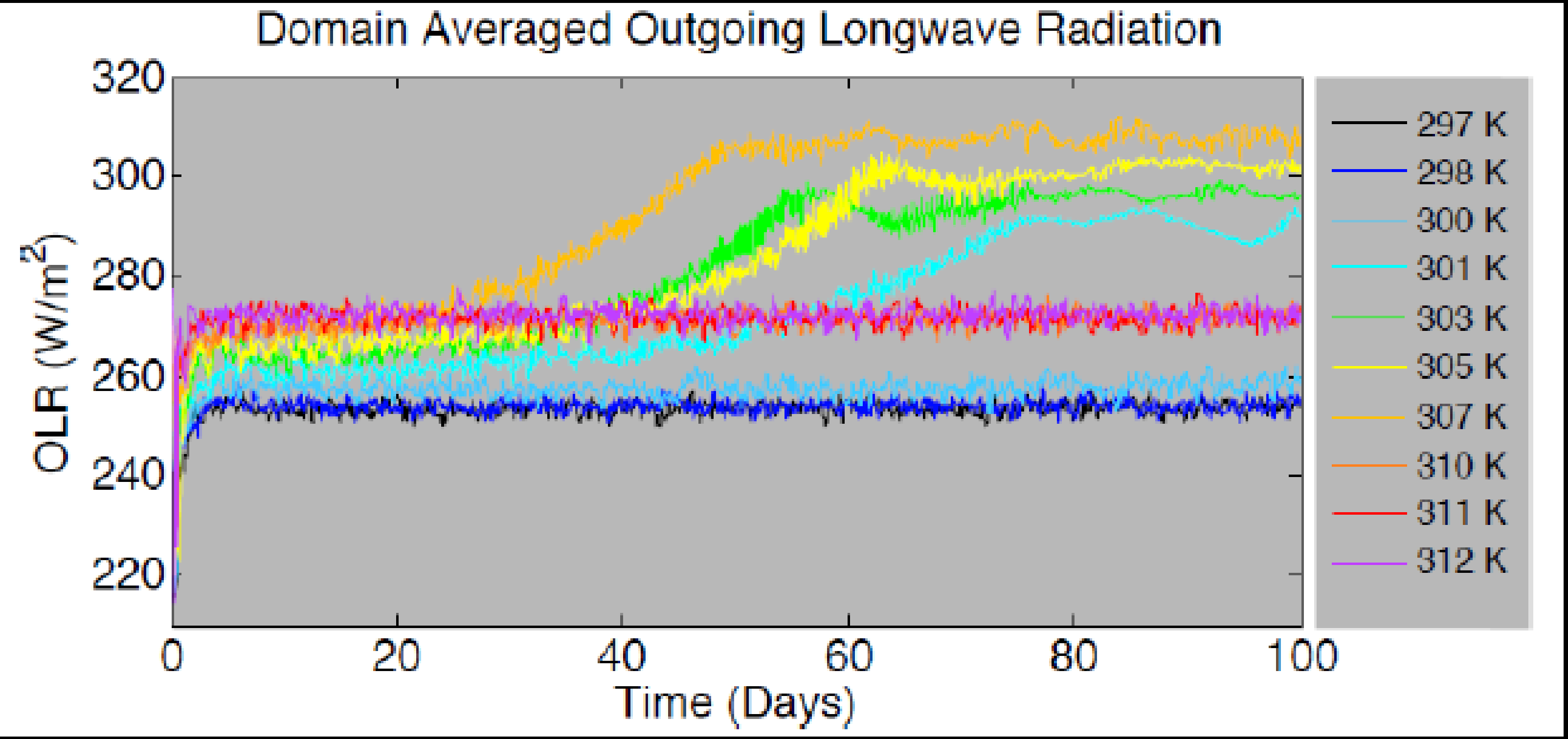


Bretherton et al, 2005

Tobin et al, 2012 ; Tobin et al, 2013

Effect on climate sensitivity ?

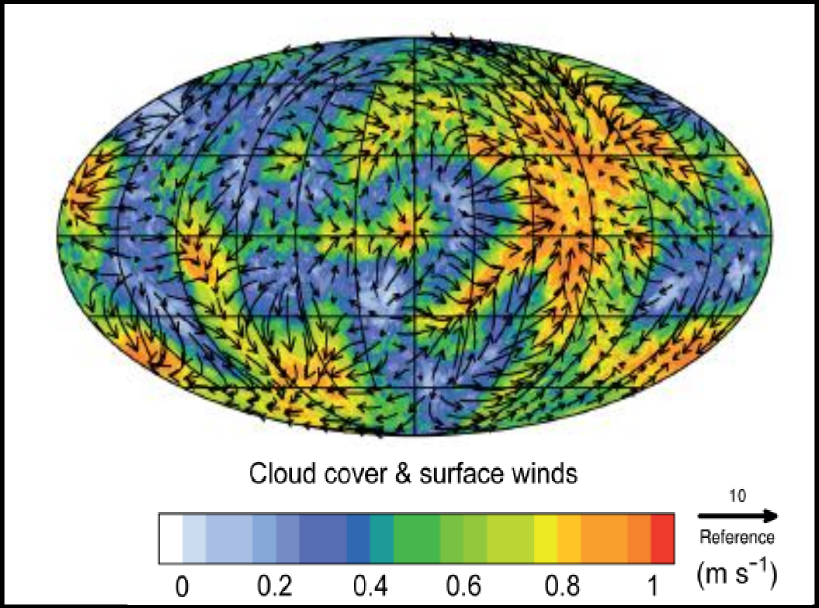
In CRMs, dependence on Sea Surface Temperature



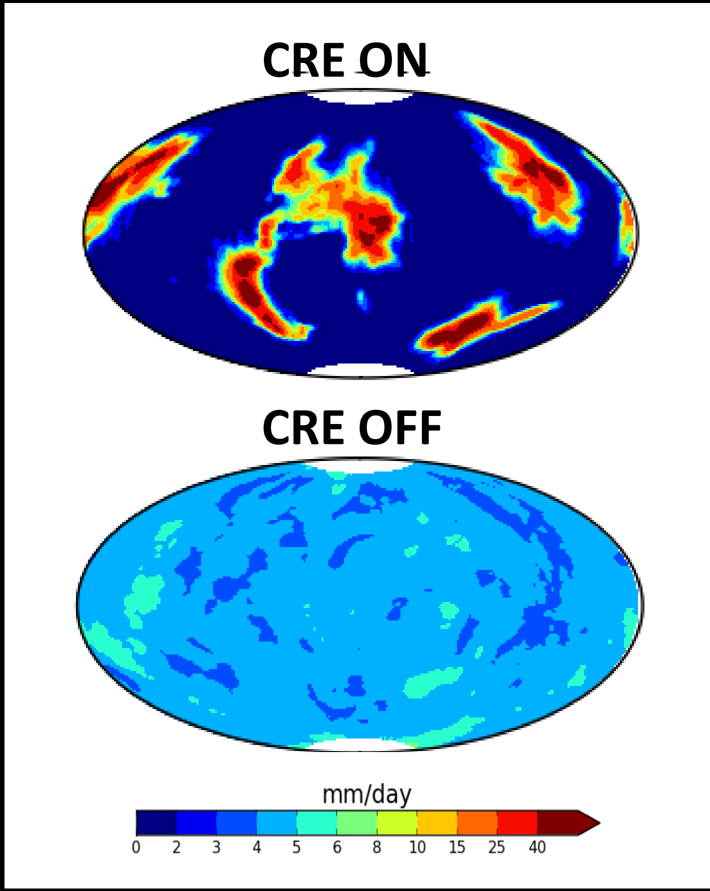
Wing and Emanuel, 2014
Khairoutdinov and Emanuel, 2010
Held et al., 1993

GCMs run in RCE configuration

RCE : aquaplanet with no rotation, uniform insolation



ECHAM6 with slab ocean



LMDZ with fixed SSTs

Popke, Stevens and Voigt, 2013
Bony, Coppin et al., in preparation

1

Conditions of self-aggregation in LMDZ

- Dependence on SST
- Dependence on initial conditions

2

Mechanisms of self-aggregation

- MSE variance budget
- Initiation at high SSTs
- Initiation at low SSTs
- Generalization ?

1

Conditions of self-aggregation in LMDZ

Dependence on SST

Dependence on initial conditions

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Mechanisms of self-aggregation

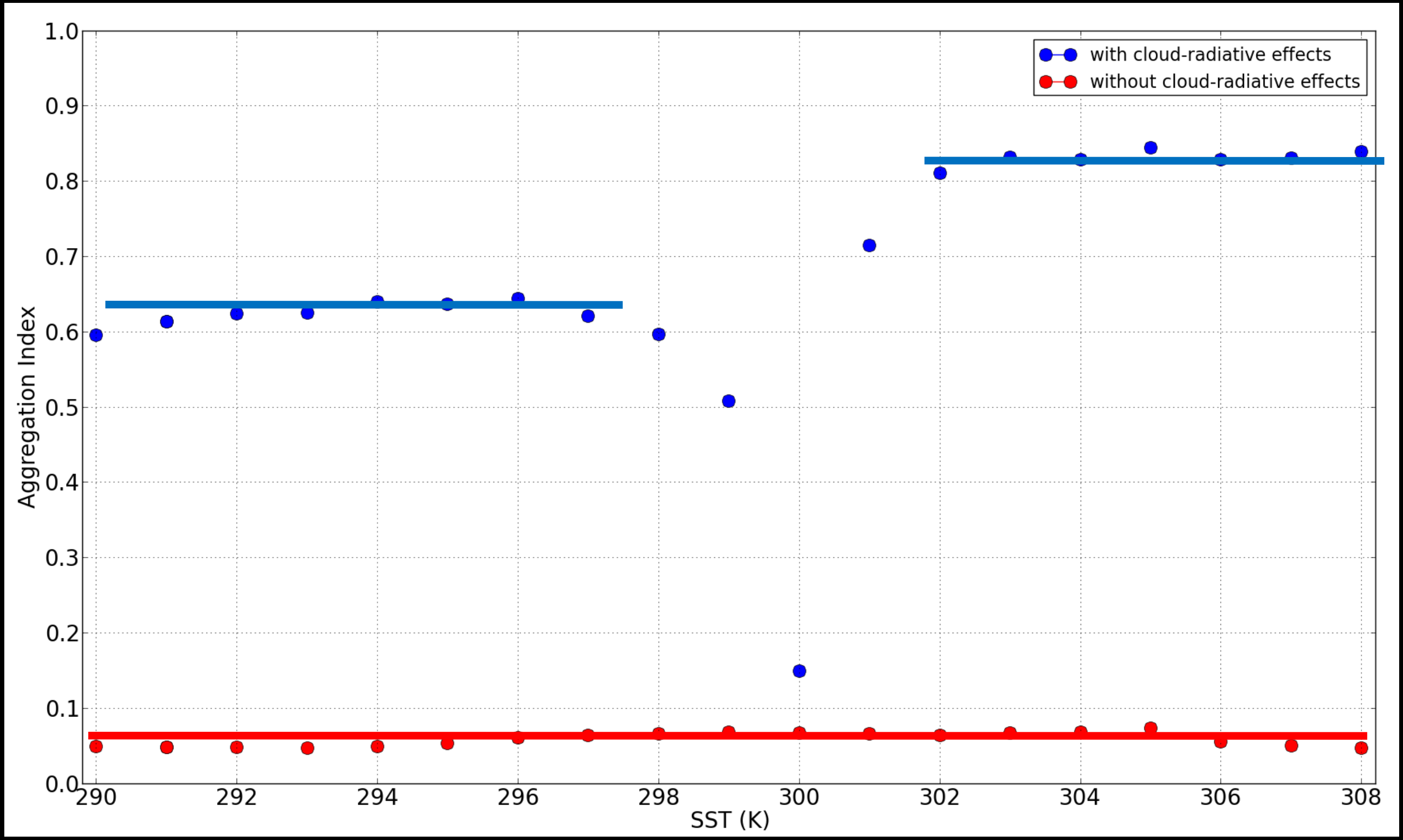
MSE variance budget

Initiation at high SSTs

Initiation at low SSTs

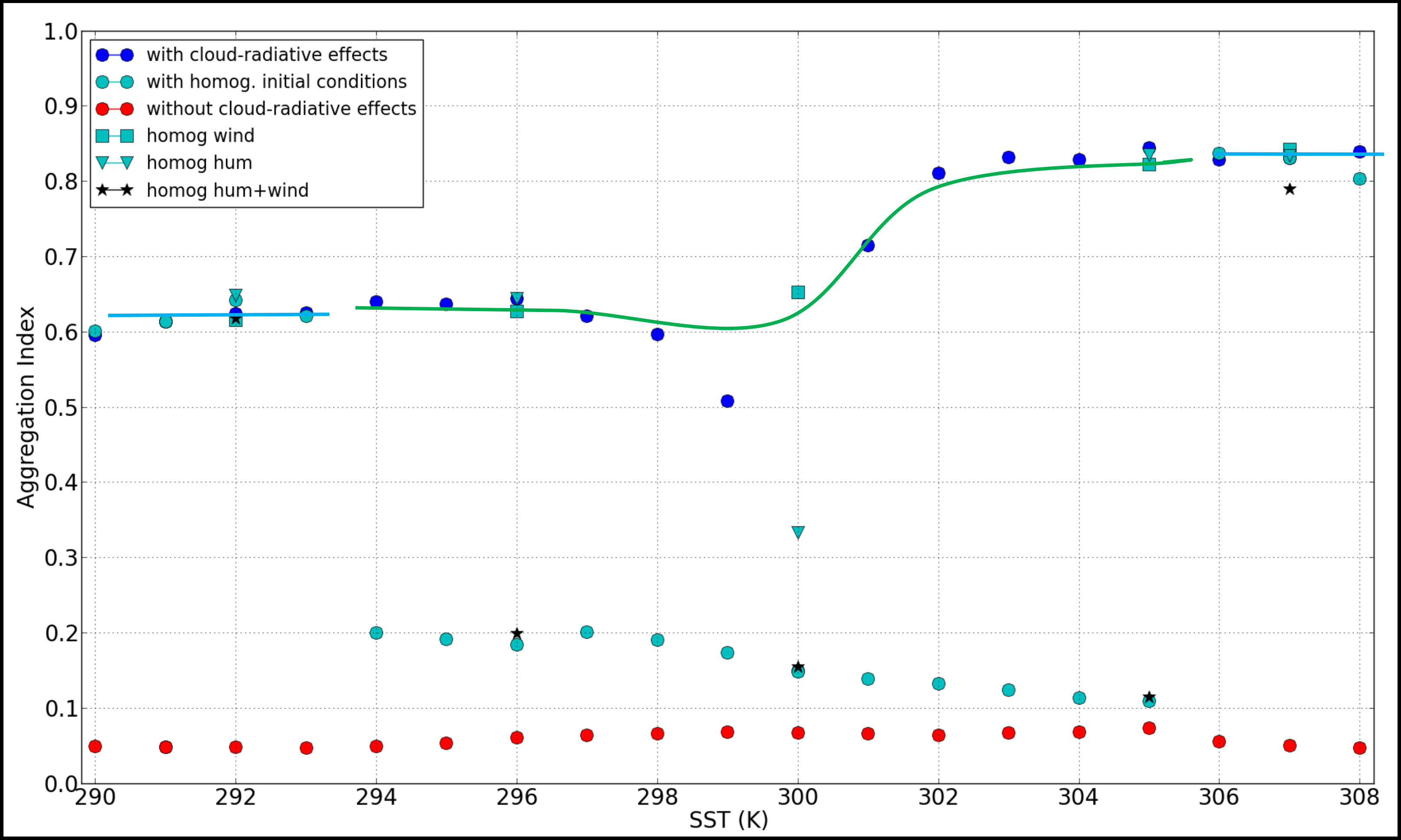
Generalization ?

Dependence on the SST



- 1 regime (with no self-aggregation) without cloud-radiative effects
- 2 different regimes with cloud-radiative effects:
  - AI = 0.65 for SST < 298K
  - SF = 0.82 for SST > 301K

Dependence on the initial conditions



- 2 different states of aggregation: more aggregated at high SST with a transition close to 300K
- 2 different states possible between 294K and 305K ≠ always aggregated below 294K and above 305K

1

Conditions of self-aggregation in LMDZ

Dependence on SST

Dependence on initial conditions

2

Mechanisms of self-aggregation

MSE variance budget

Initiation at high SSTs

Initiation at low SSTs

Generalization ?

Moist Static Energy budget

Use of the methodology developed by Wing and Emanuel (2014): moist static energy (MSE) budget:

- MSE variance increases as self-aggregation progresses
- its mass-weighted vertical integral can only be changed by radiation, surface fluxes and horizontal advection

$$\frac{1}{2}\frac{\partial \hat{h}'^2}{\partial t} = \hat{h}' SEF' + \hat{h}' NetSW' + \hat{h}' NetLW' + \hat{h}'\nabla_h . \widehat{\vec{u}h}$$

Correlation of ĥ' and anomaly of Surface Enthalpy Fluxes

Correlation of ĥ' and anomaly of column SW rad. flux convergence

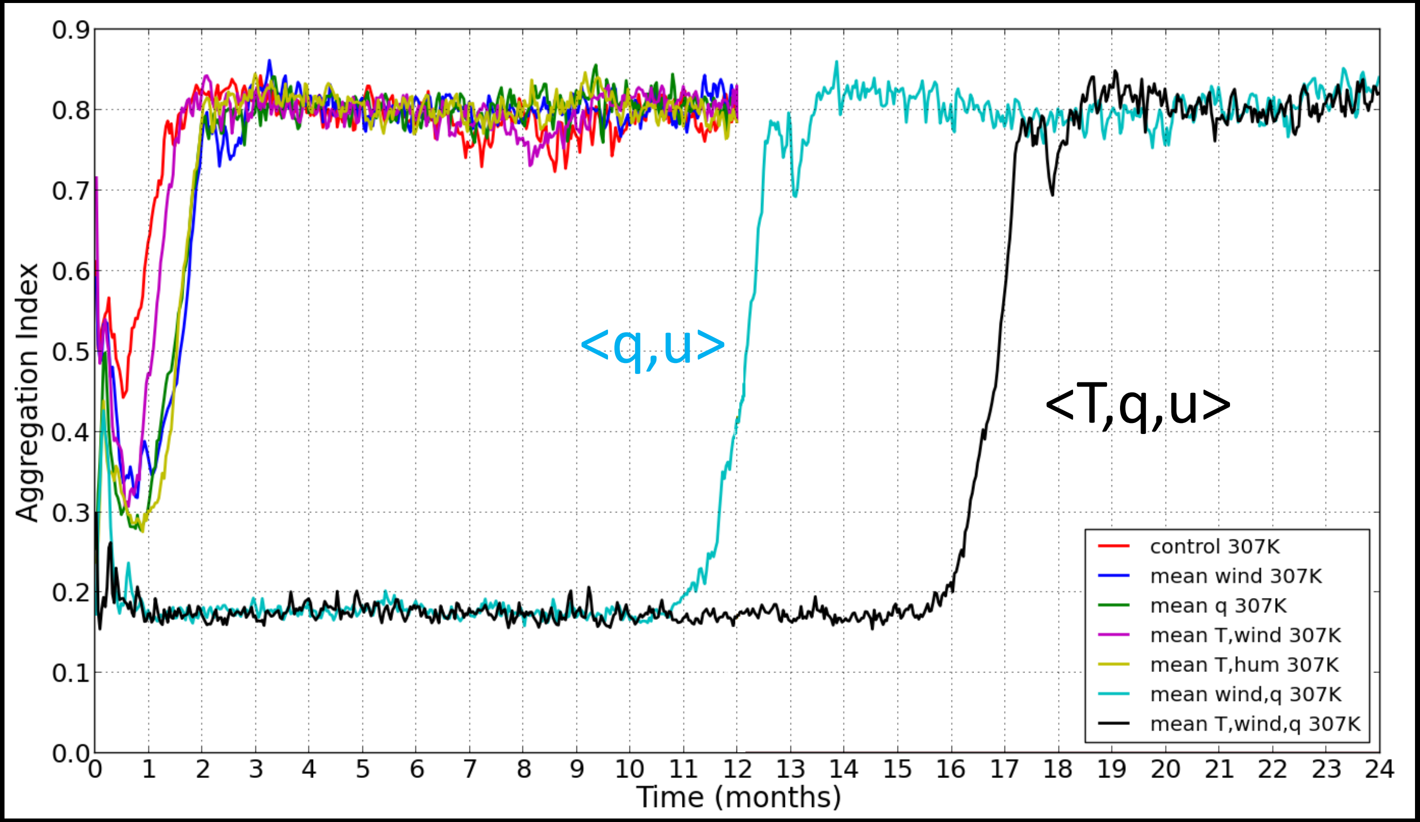
Correlation of ĥ' and ano. of column LW rad. flux convergence

Correlation between ĥ and horizontal div. of density-weighted vertical integral of flux of MSE

Initiation at high SST

Objective: detect factors related to the initiation

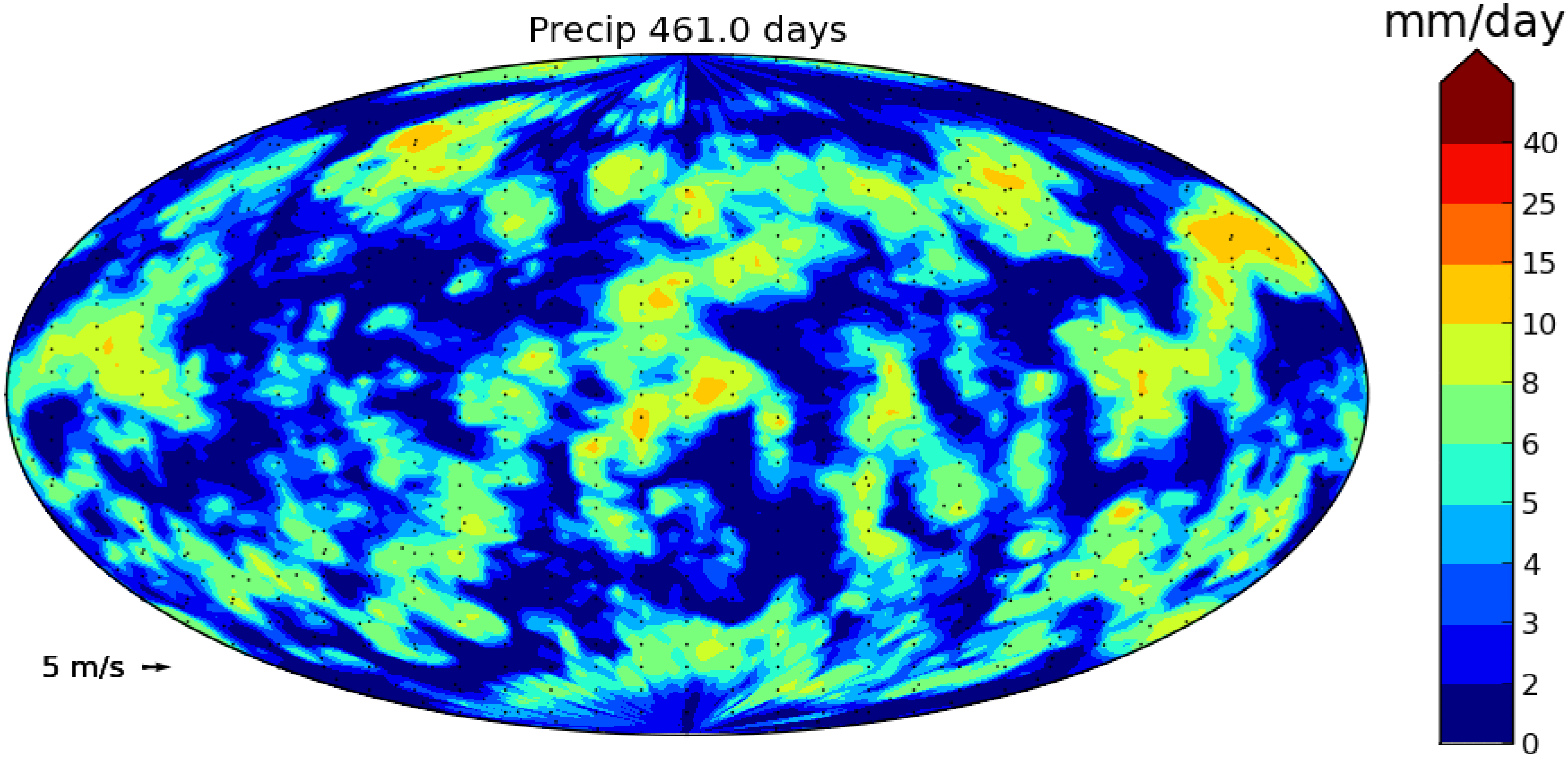
➔ test effect of mean T and/or wind and/or humidity profiles at the beginning



Sensitivity to the wind and humidity **together** → **Convergence of humidity ? WISHE ? Radiative feedback ?**

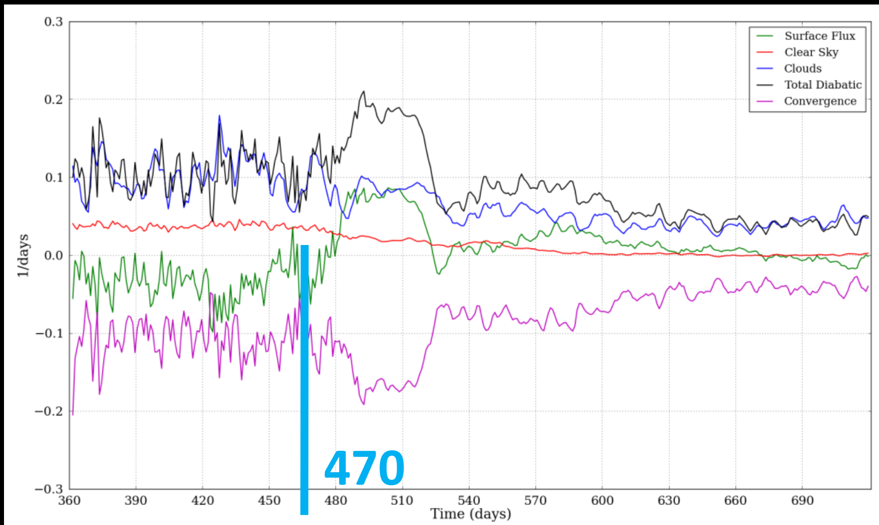
Not sensitive to temperature (in any case), to wind or humidity alone

Initiation at high SST

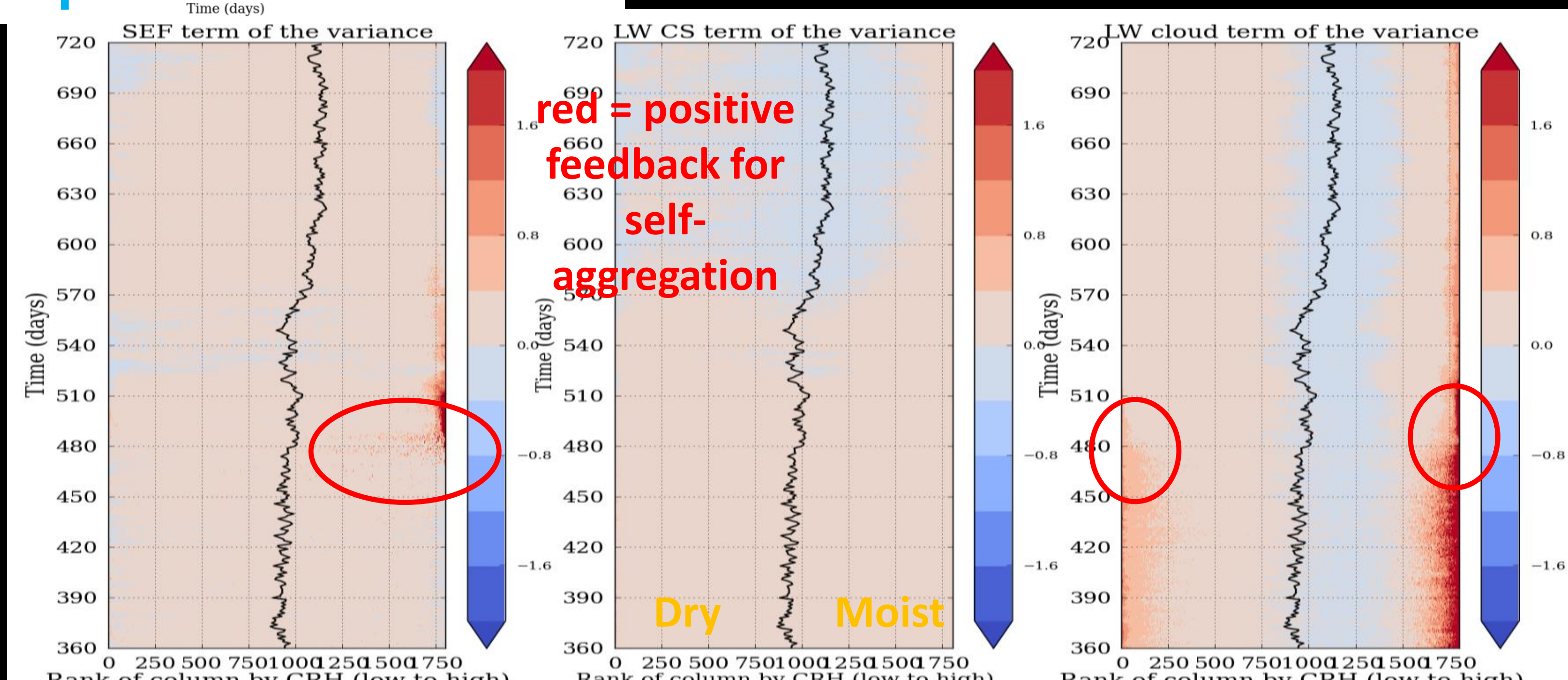


Initiation starts at day 480.

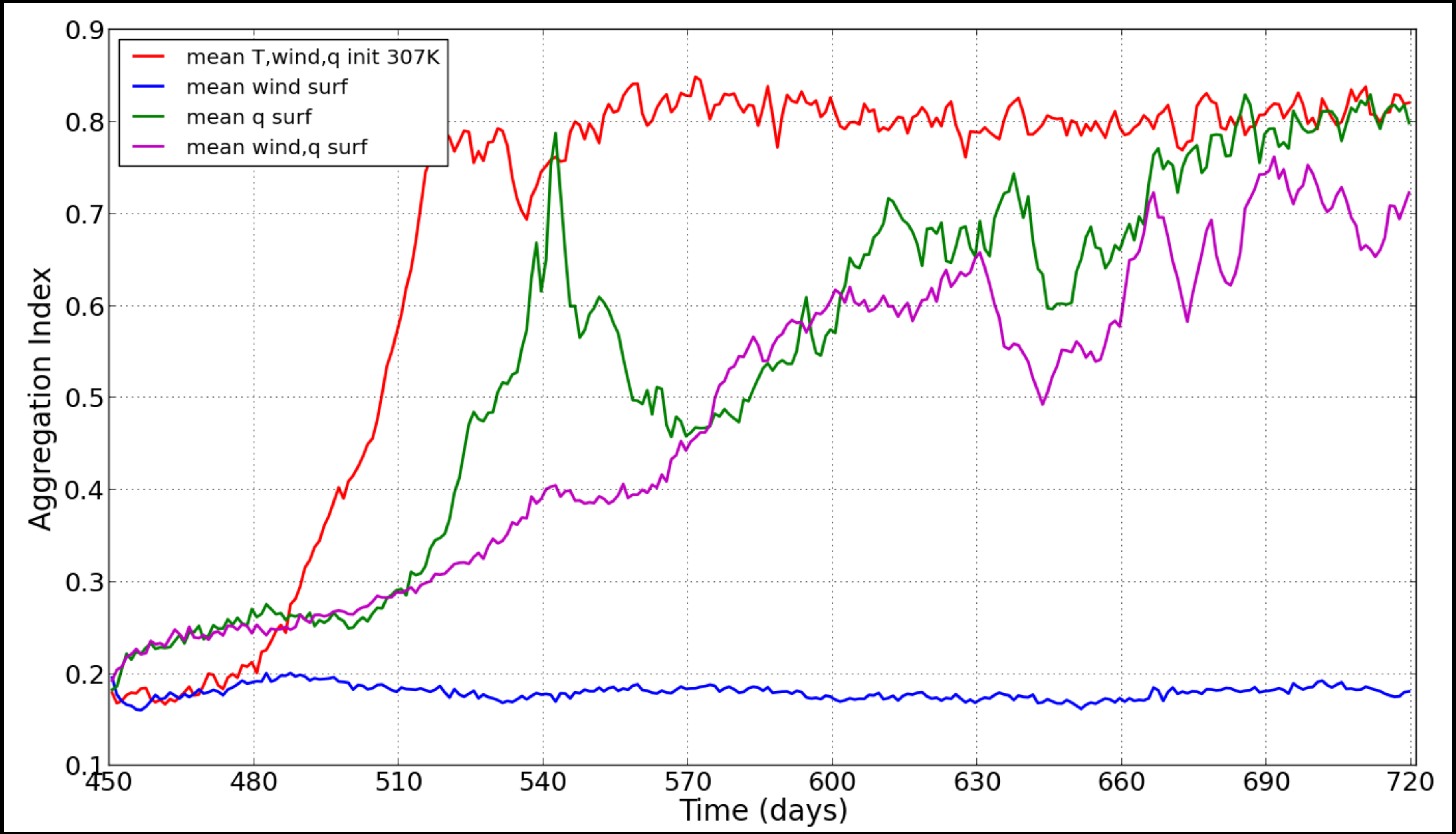
Key parameters for the initiation



- Positive feedback in the surface fluxes close to 470 days
- Strong positive cloud feedback in the cloudy regions all along



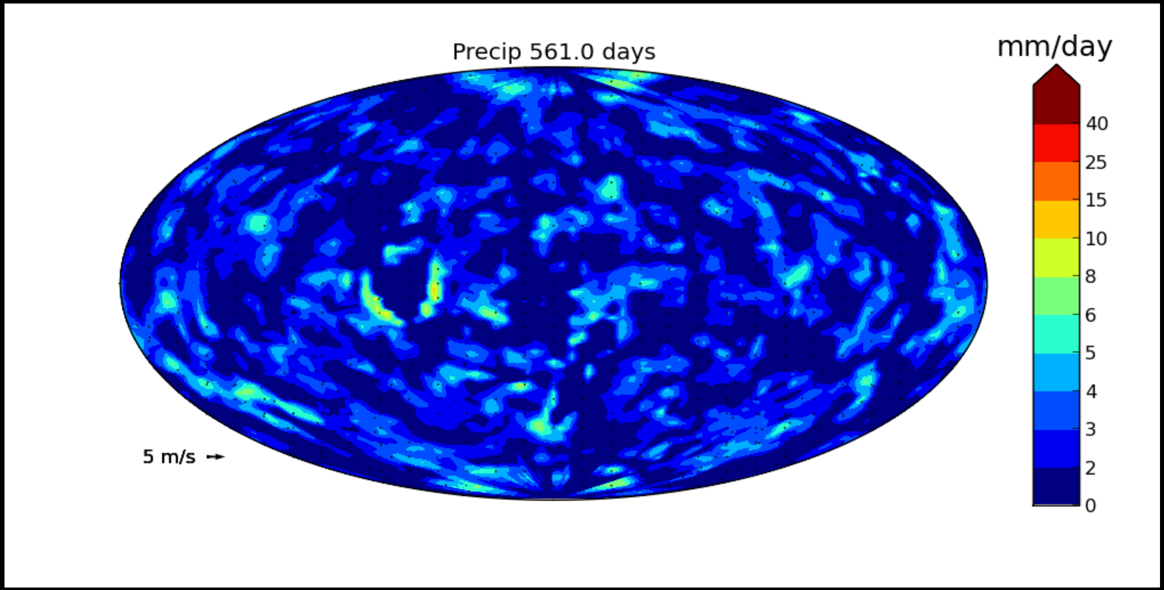
Experiments to test the role of WISHE

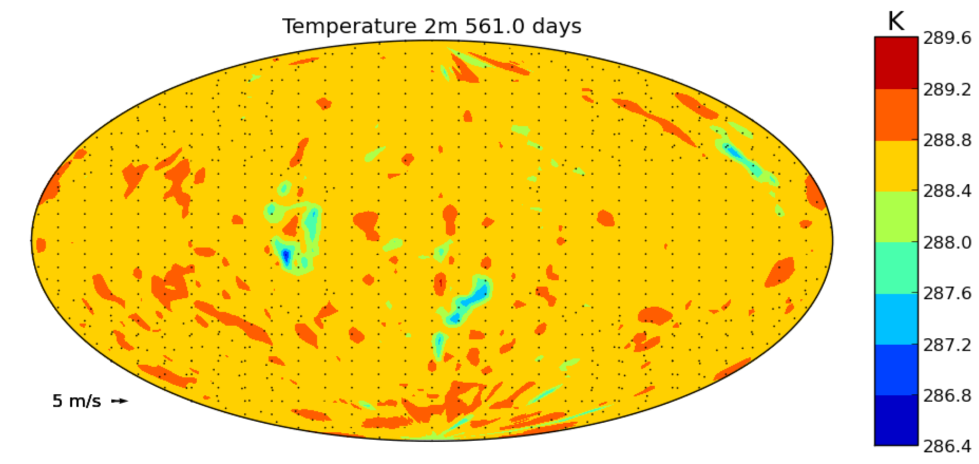


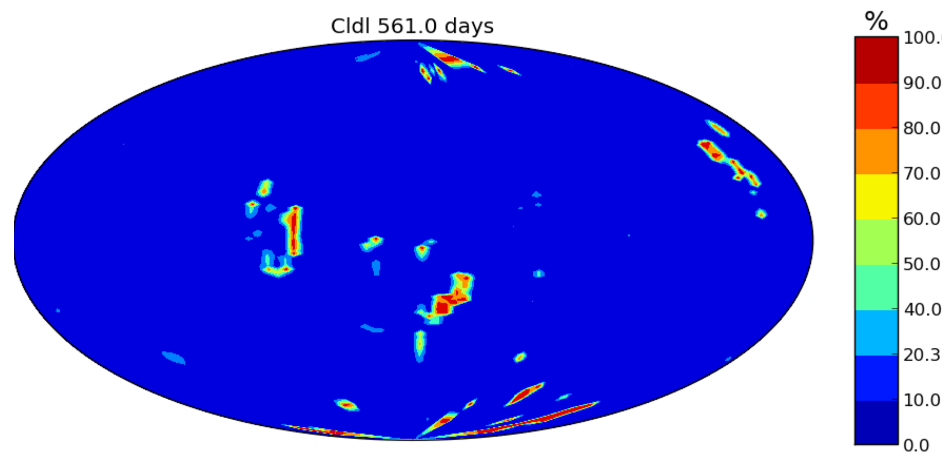
Surface wind homogeneized before boundary layer code → no self-aggregation

→ Surface wind crucial for the initiation (Wind Induced Surface Heat Exchange feedback)

Initiation at low SST

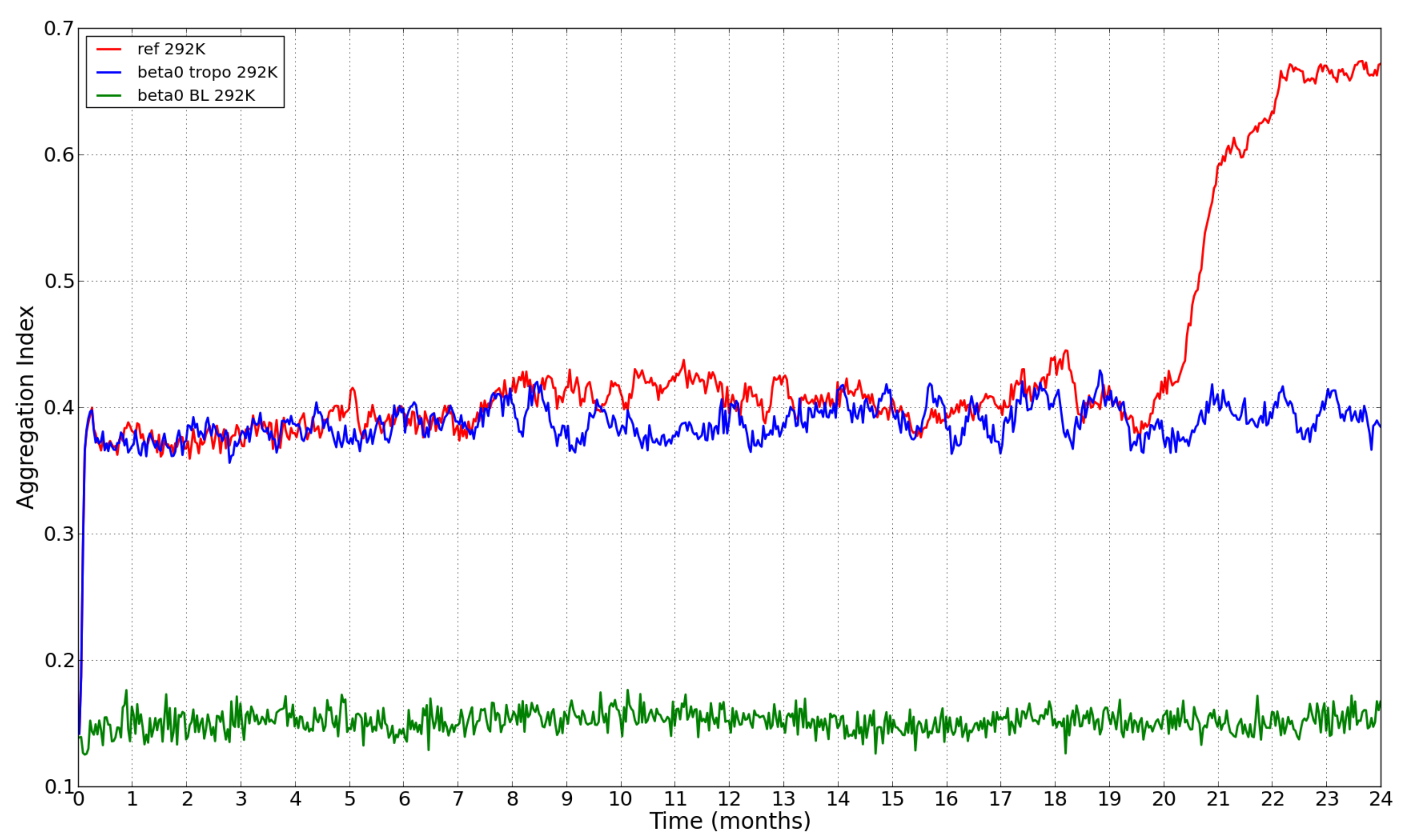






Initiation starts at day 600.

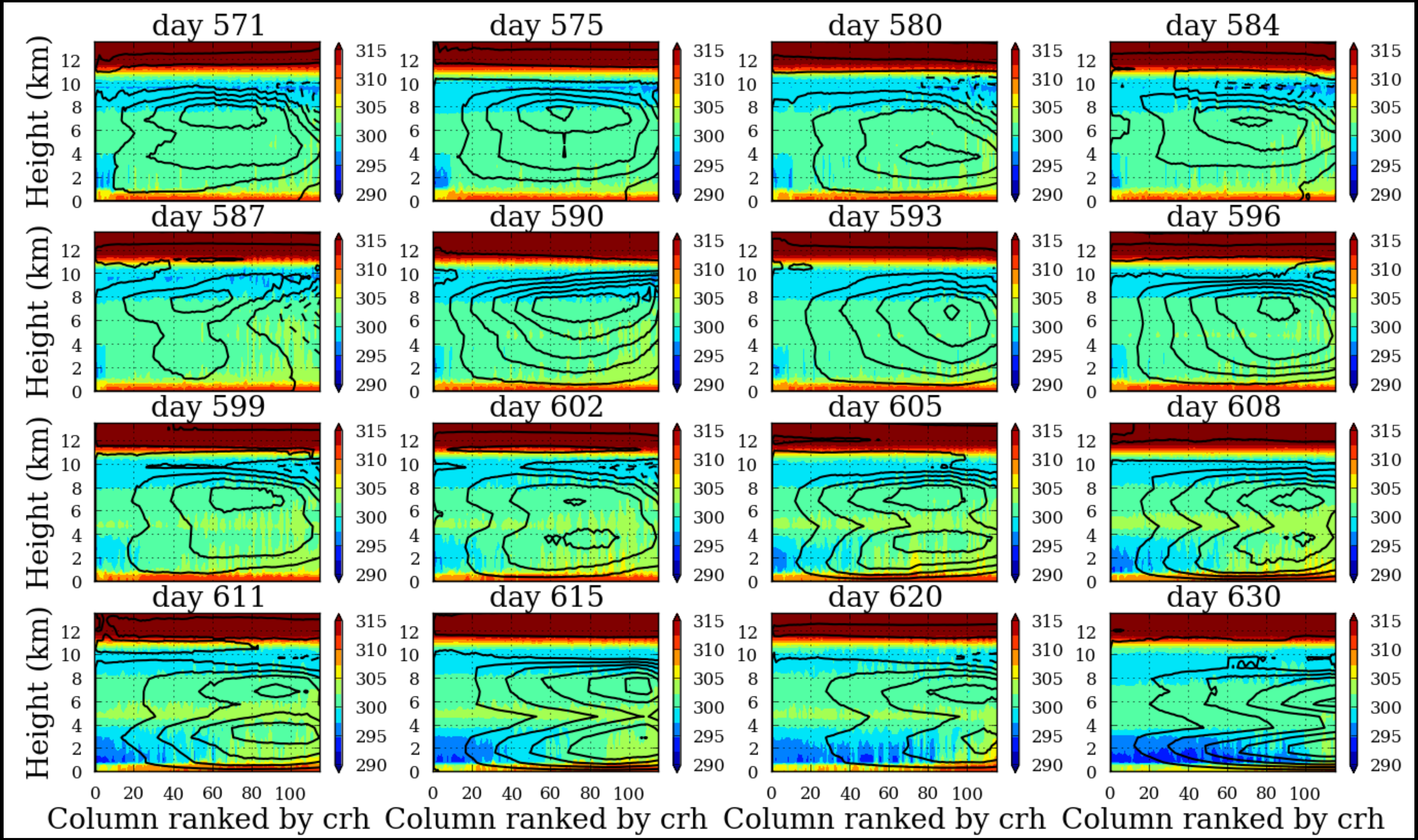
Processes linked to the initiation at low SST



Without cloud-radiative effects in the boundary layer : no self-aggregation at all

Radiative effect of low clouds crucial for the initiation of self-aggregation

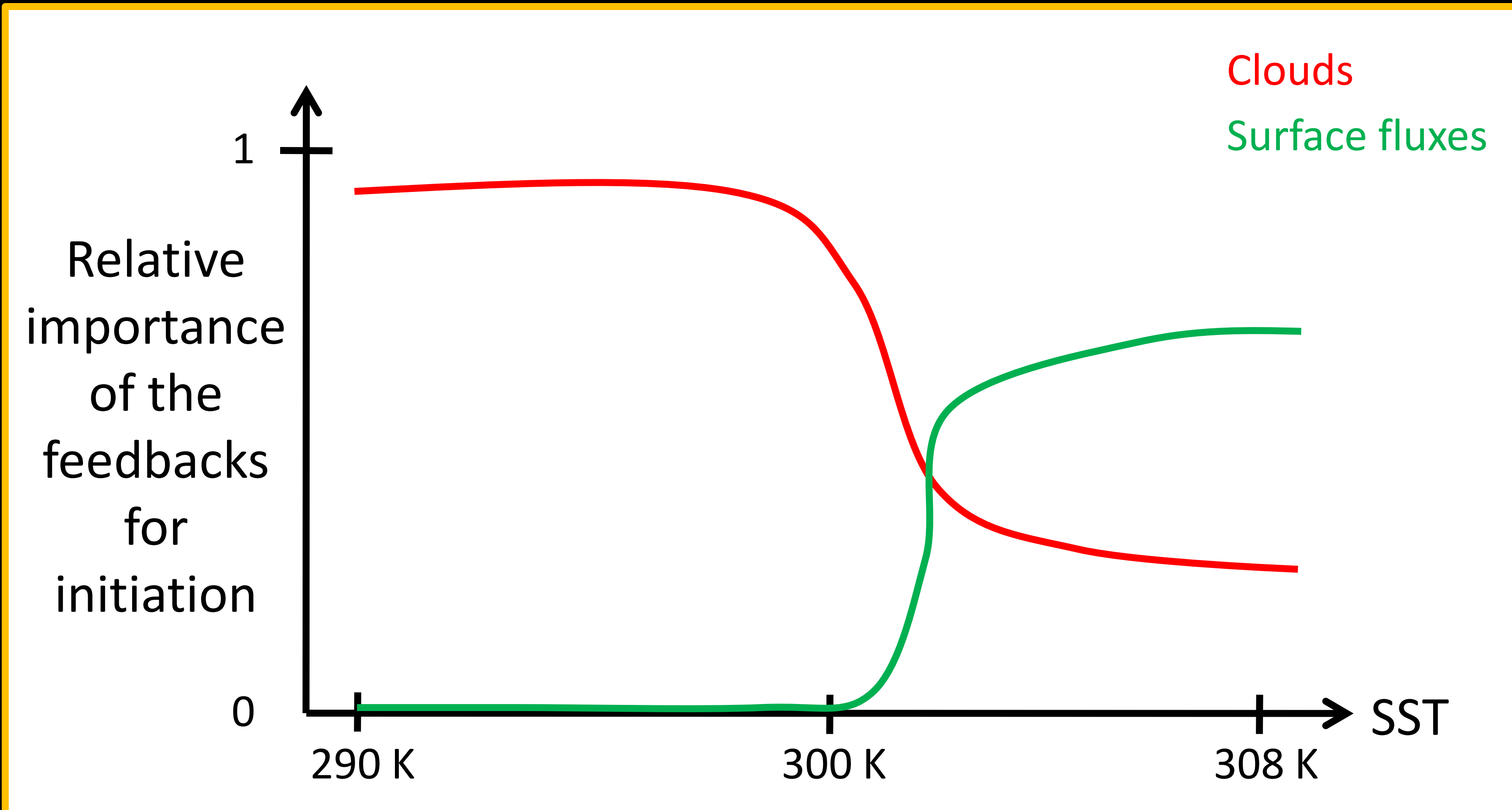
Initiation at low SST



- Low-level circulation related to low clouds when initiation starts
- Up-gradient flux of MSE to the moist regions

Can we generalize ?

Idea: Generalize the study of initiation at each SST to quantify the importance of each feedback



Can we generalize ?

Still in progress !

Conclusion

- 2 different states of aggregation: at low and high SST
- In between: aggregated or disaggregated depending on the initial conditions (maybe due to hysteresis close to transition)

At high Sea Surface Temperature:

- Initiation related to the WISHE feedback
- Radiative effects: not very important for initiation

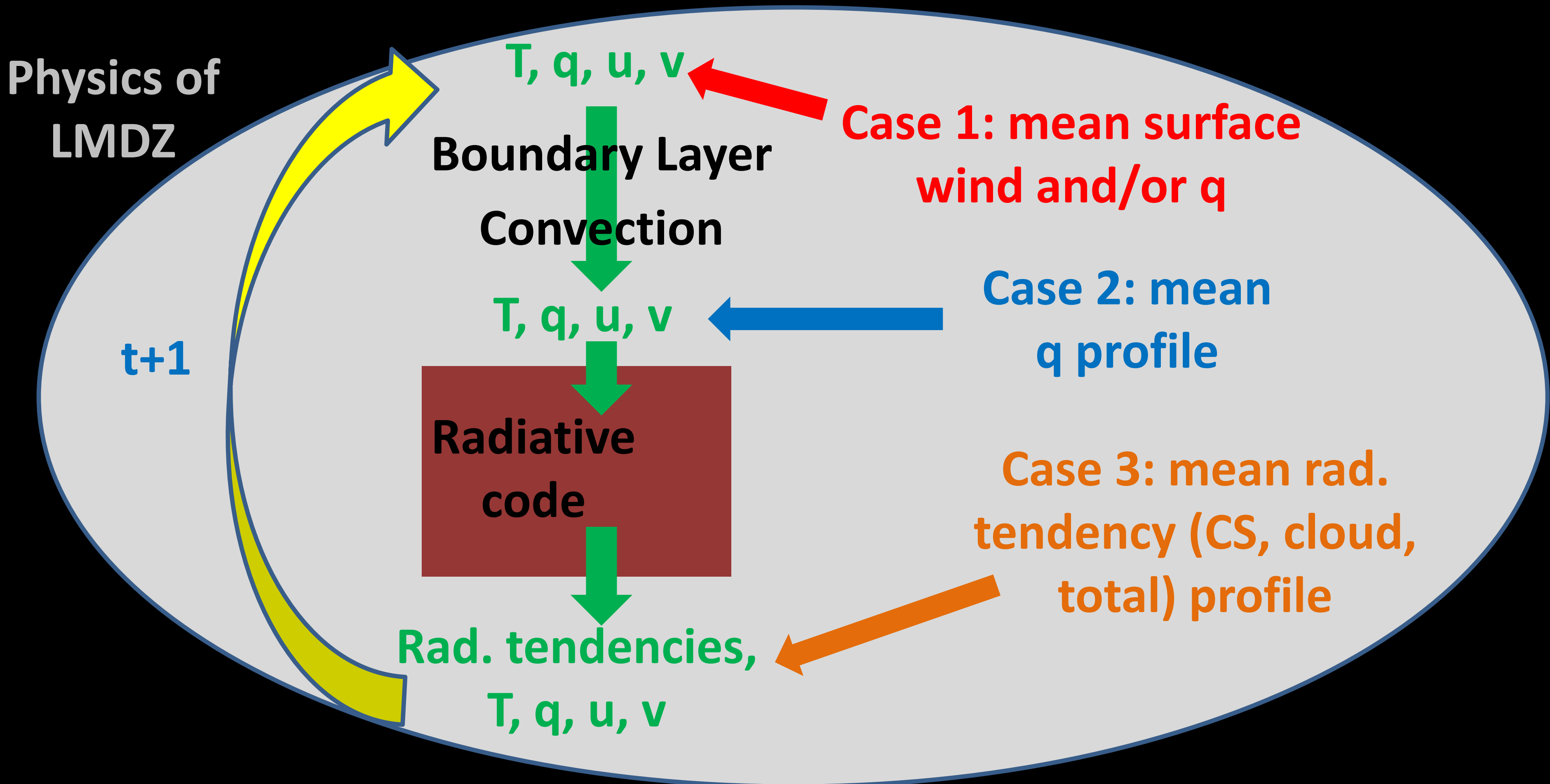
At low SST:

- No role of WISHE
- Radiative effects of clouds, espcially those due to low clouds, are crucial

Thank you for your attention !

Methodology

Homogenization Experiments



How can we characterize self-aggregation in a GCM ?

Aggregation index (AI)

$$AI = SF \times \Delta q$$

$$SF = \frac{areas\,(w_{500} > 0)}{total}$$

$0.5 < SF < 1$

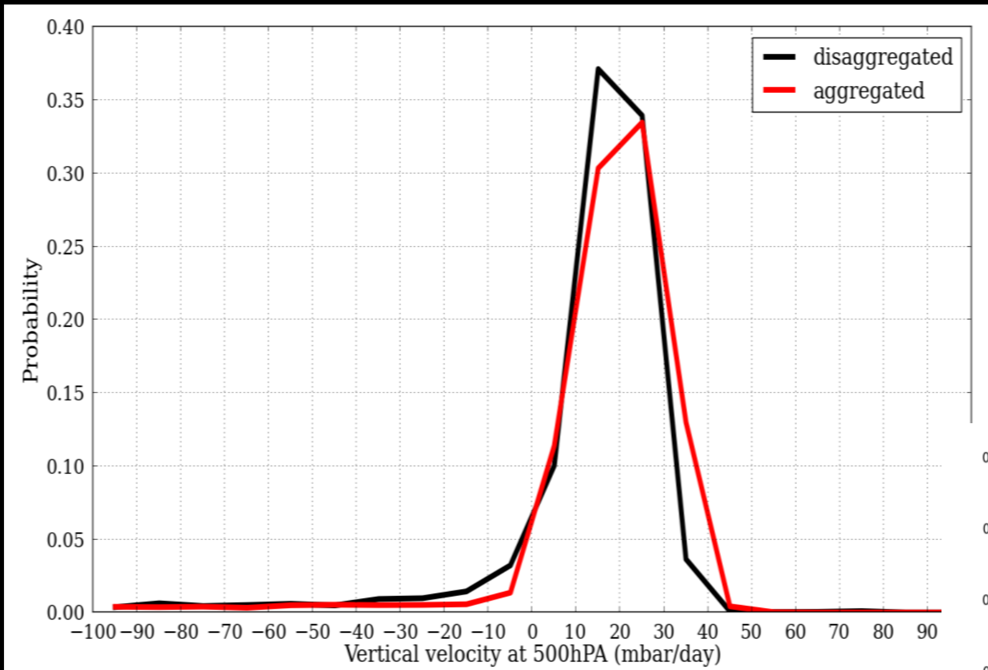
$$\Delta q = \frac{q_{90th} - q_{10th}}{q_{90th}}$$

$0 < \Delta q < 1$

Future

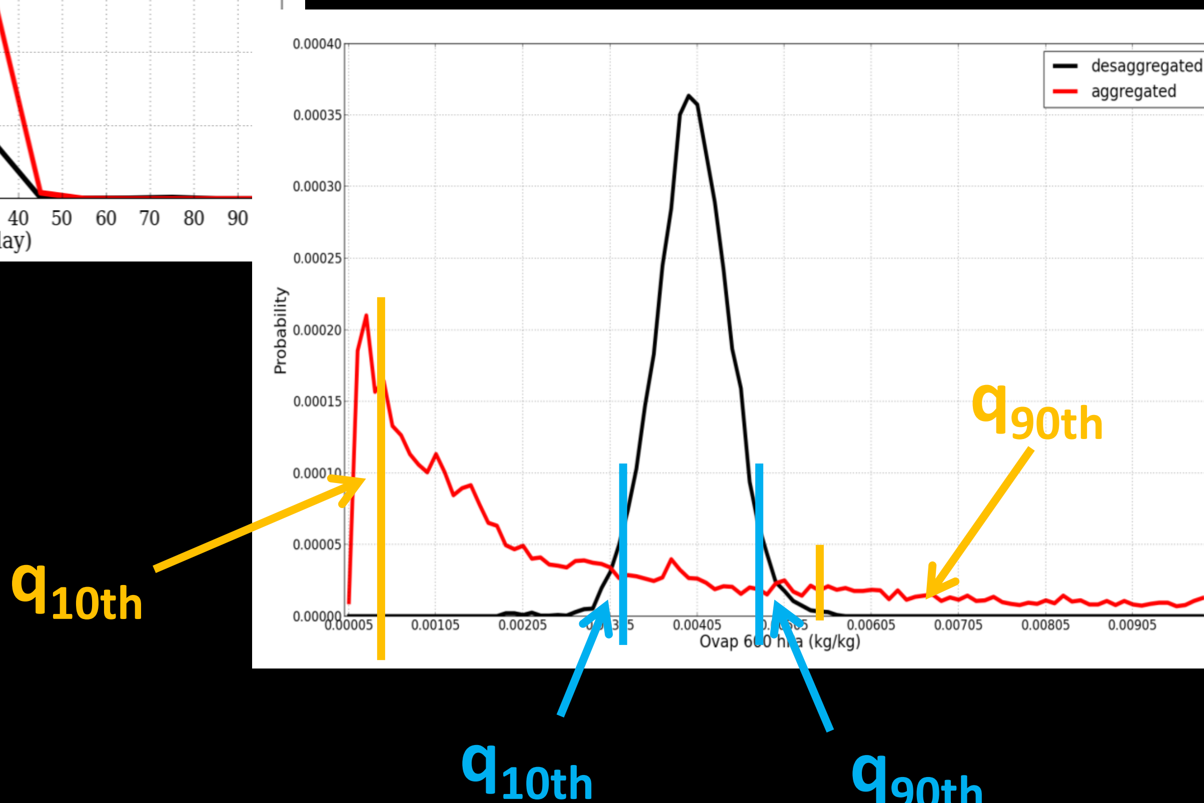
➔ Complete the study on the initiation of self-aggregation : understand the role of the coupling between wind and humidity
➔ Study of the stationarity of self-aggregation (3-6 months)
➔ Understand why there is no aggregation when no CRE

Detail on the Aggregation Index

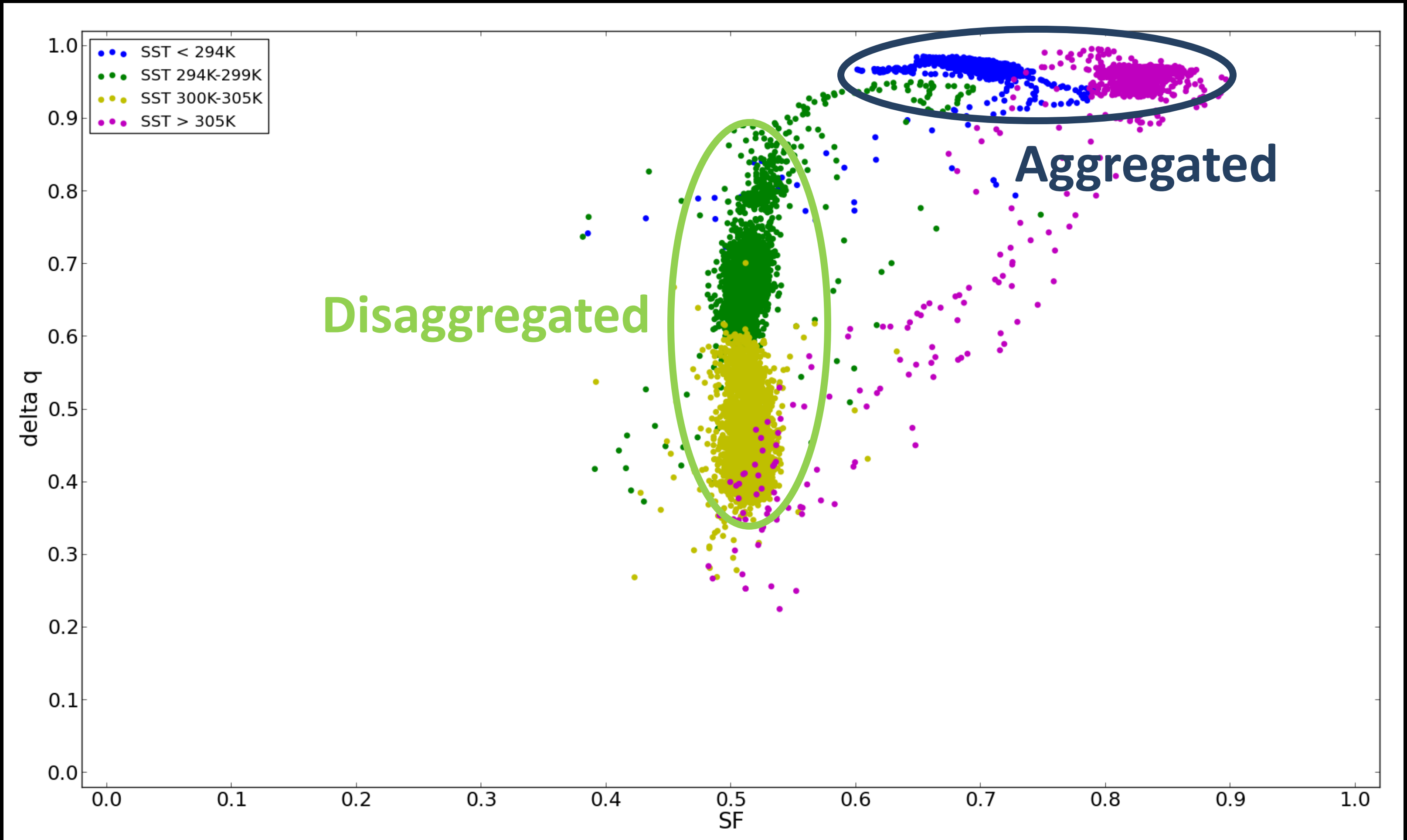


w_{500}

Humidity at 600 hPa



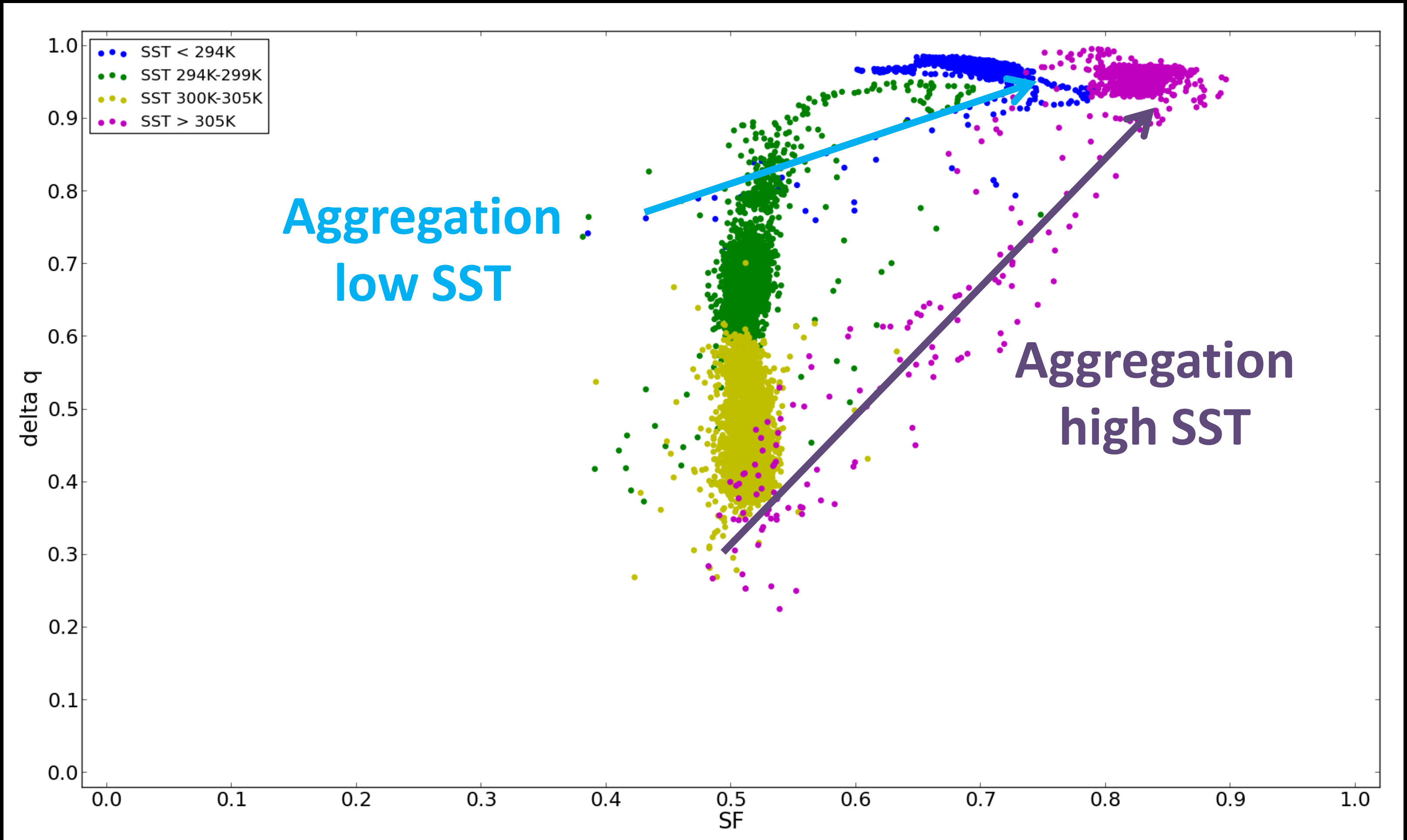
Relation between Δq and SF



<u>Equilibrium</u> : - Aggregated : $\Delta q \approx 0.95$ for $0.6 < SF < 0.9$

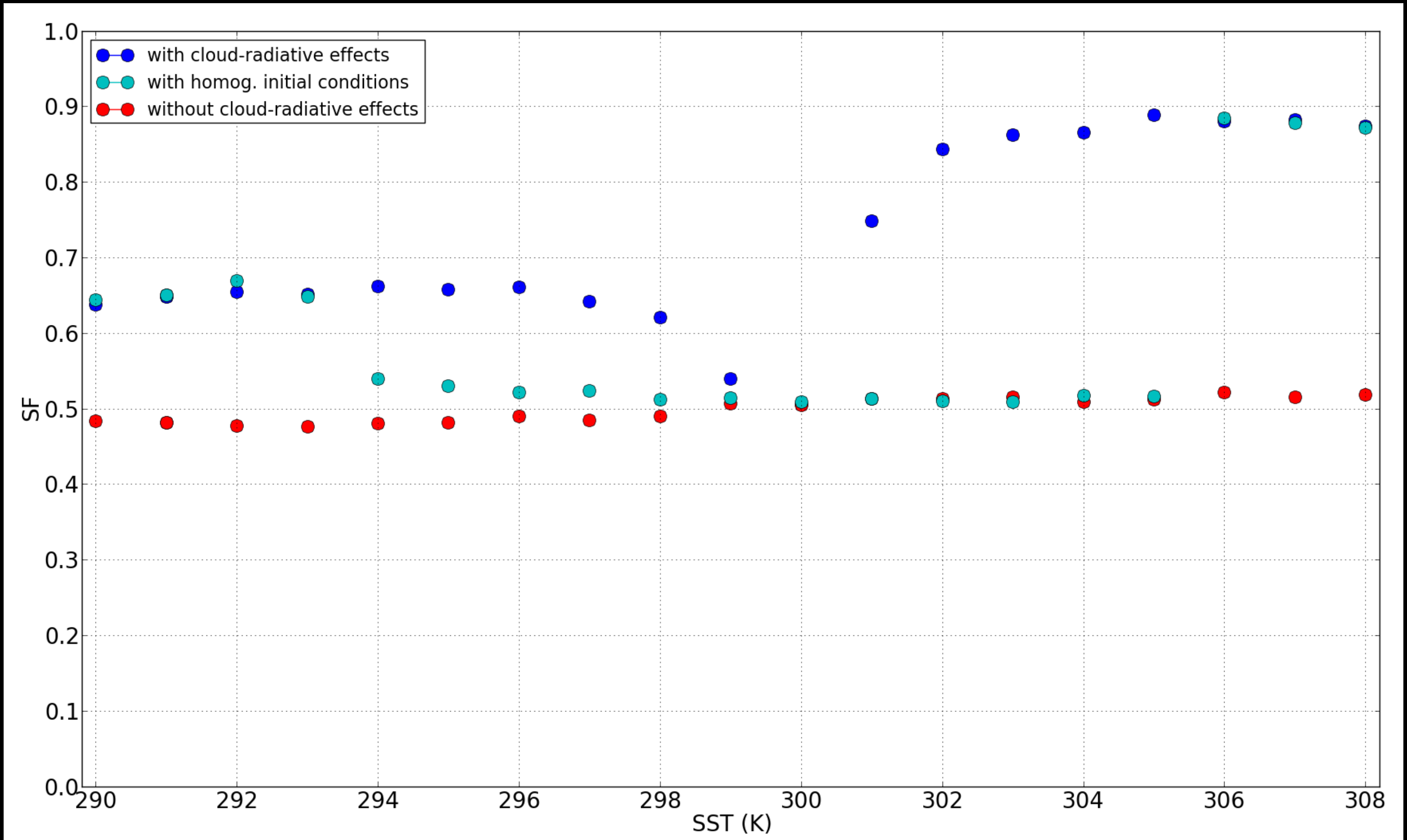
- Disaggregated : $SF \approx 0.5$ for $0.3 < \Delta q < 0.9$

Relation between Δq and SF



Different trends of aggregation according to the SST

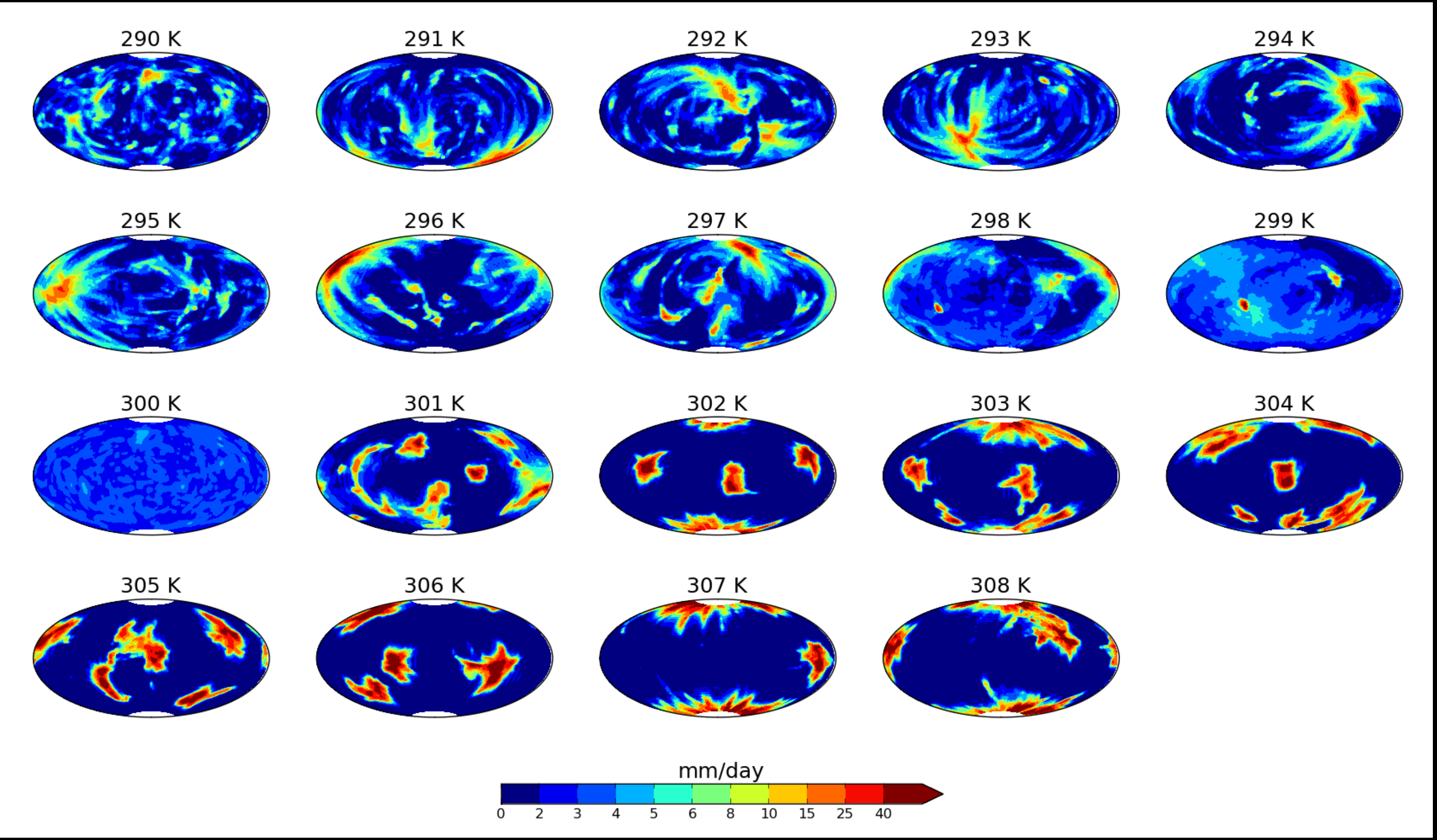
With SF only ?



No distinction between simulations without CRE and simulations which does not aggregate.

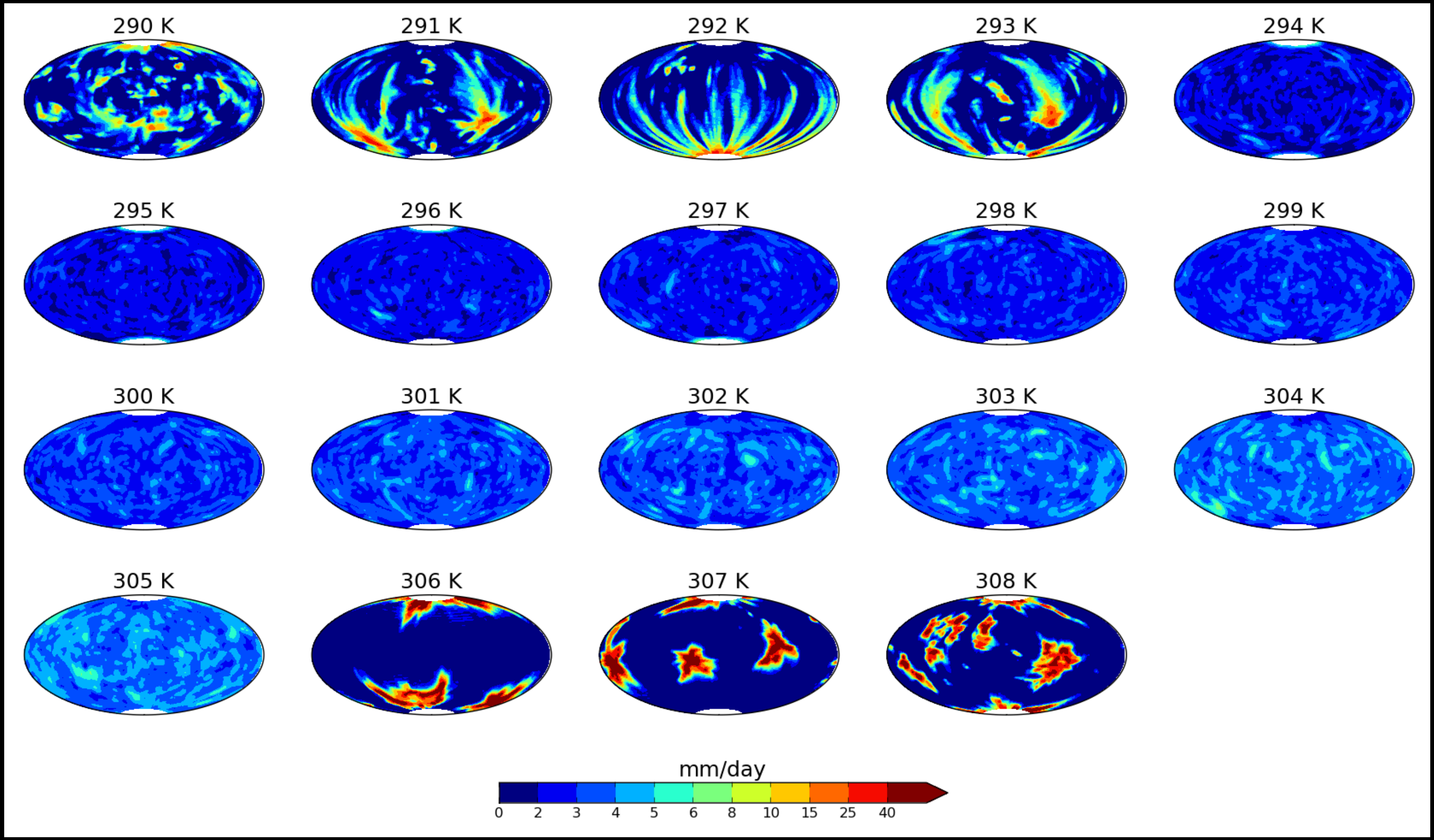
Dependence on SST

- Aquaplanet of LMDZ5A in RCE, with no rotation, uniform insolation, uniform SSTS
- Same initial conditions : last day of a run at 299K with slab ocean but different SST

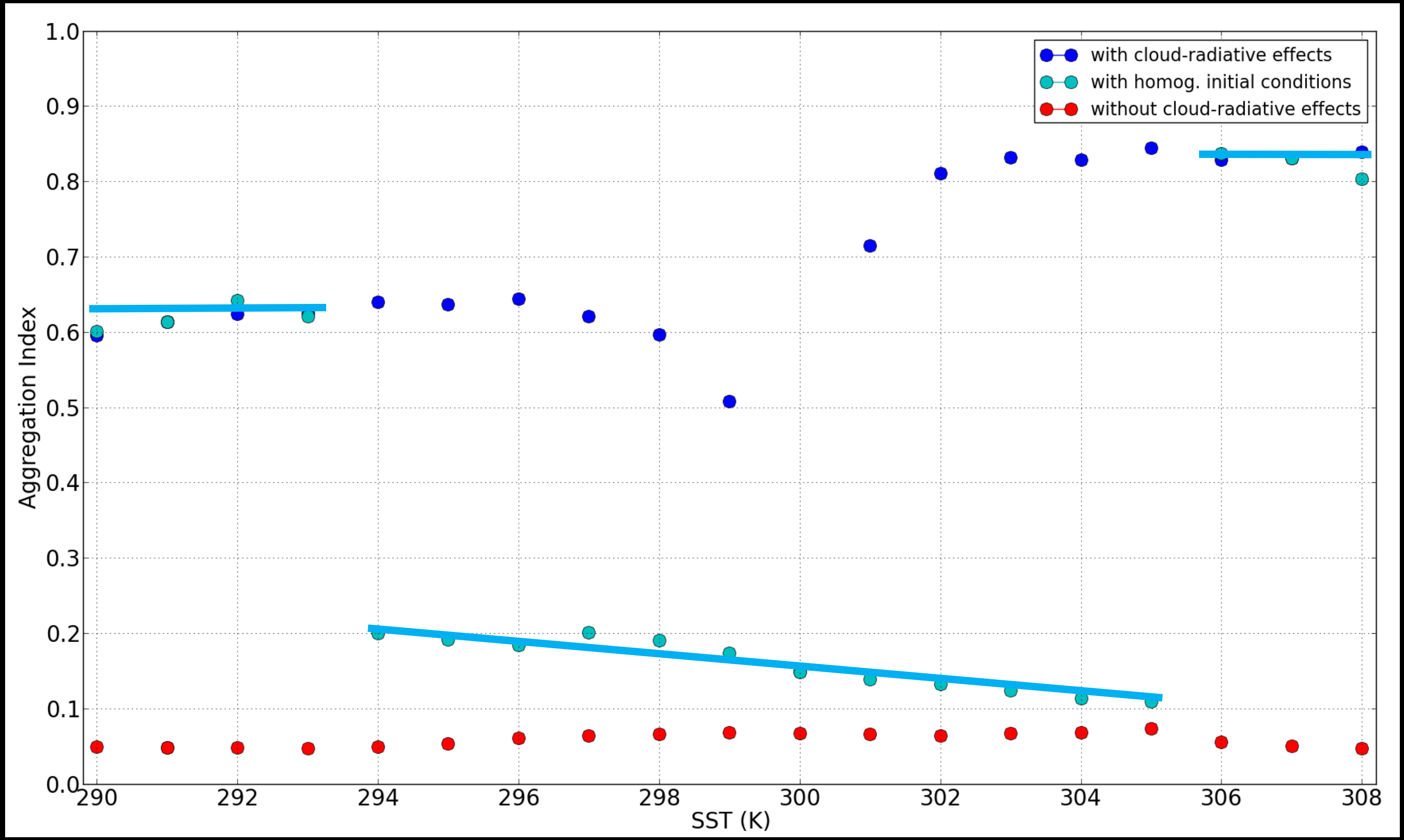


Dependence on the initial conditions

Same but for homogeneous initial conditions : last day of a simulation at the same fixed SST with spatially homogeneous T, wind and humidity profiles ; white noise for humidity at 600 hPa.



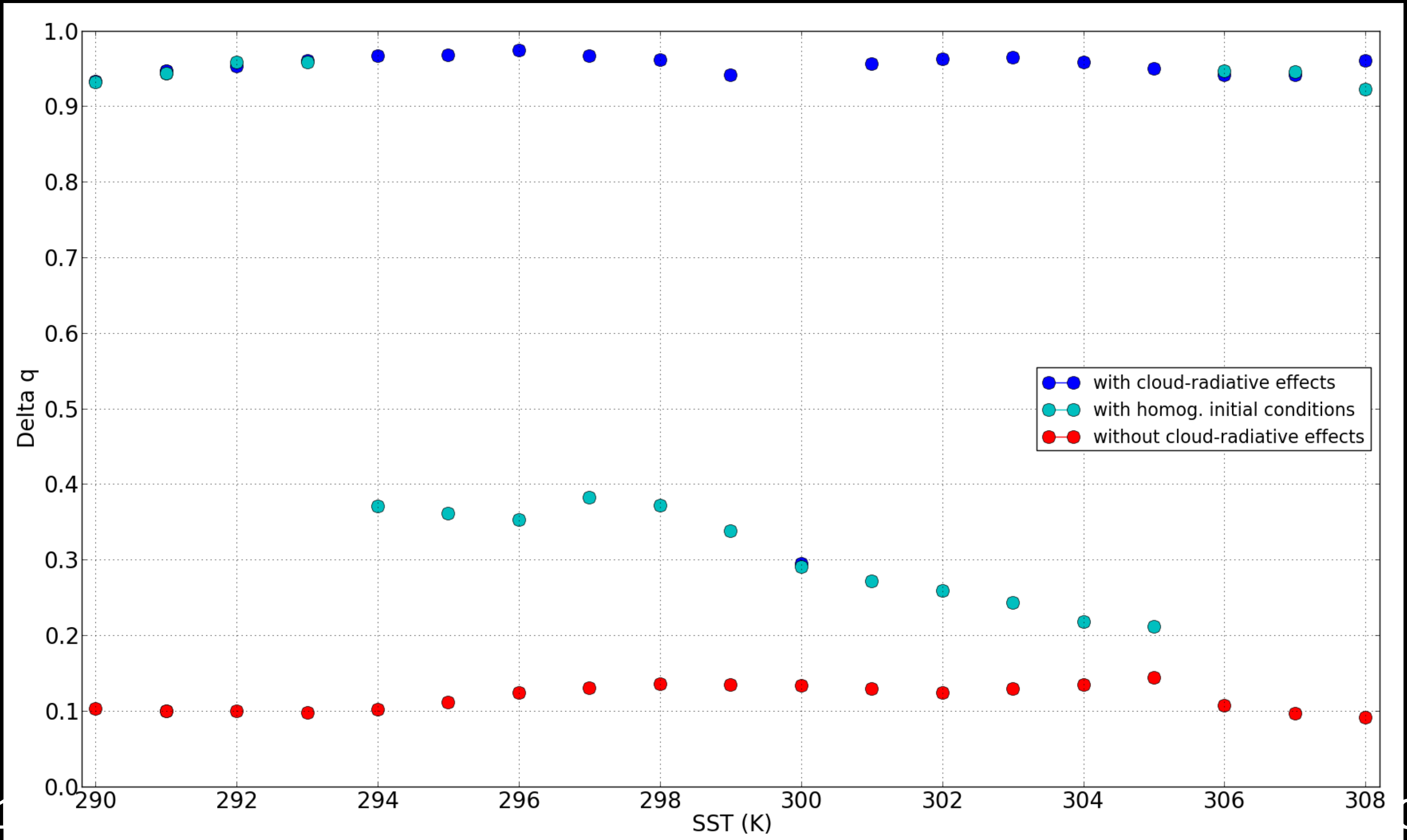
Dependence on the initial conditions



With homogeneous initial conditions (on T, wind, q) + white noise for $q_{600\ hPa}$

- Same regimes for SST<294K (AI = 0.6) and for SST>305K (AI = 0.8)
- No self-aggregation between 294K and 305K

Dependence on the conditions



• 1 … 05

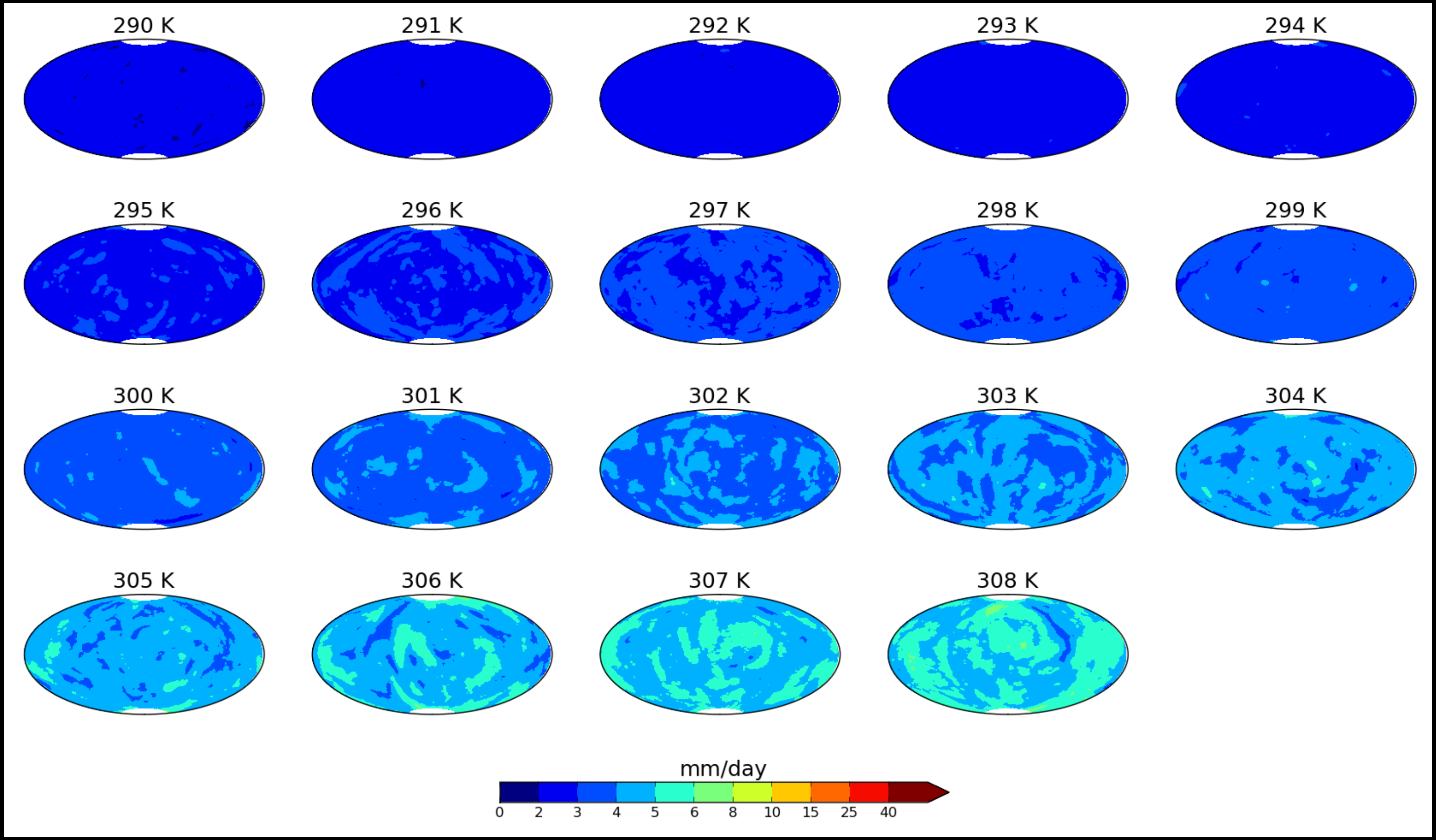
• 2 regimes with cloud-radiative effects:

  • AI = 0.6 for SST<294K
  • AI = 0.8 for SST>305K

• A lot of different states possible between 294K and 305K

Dependence on the initial conditions

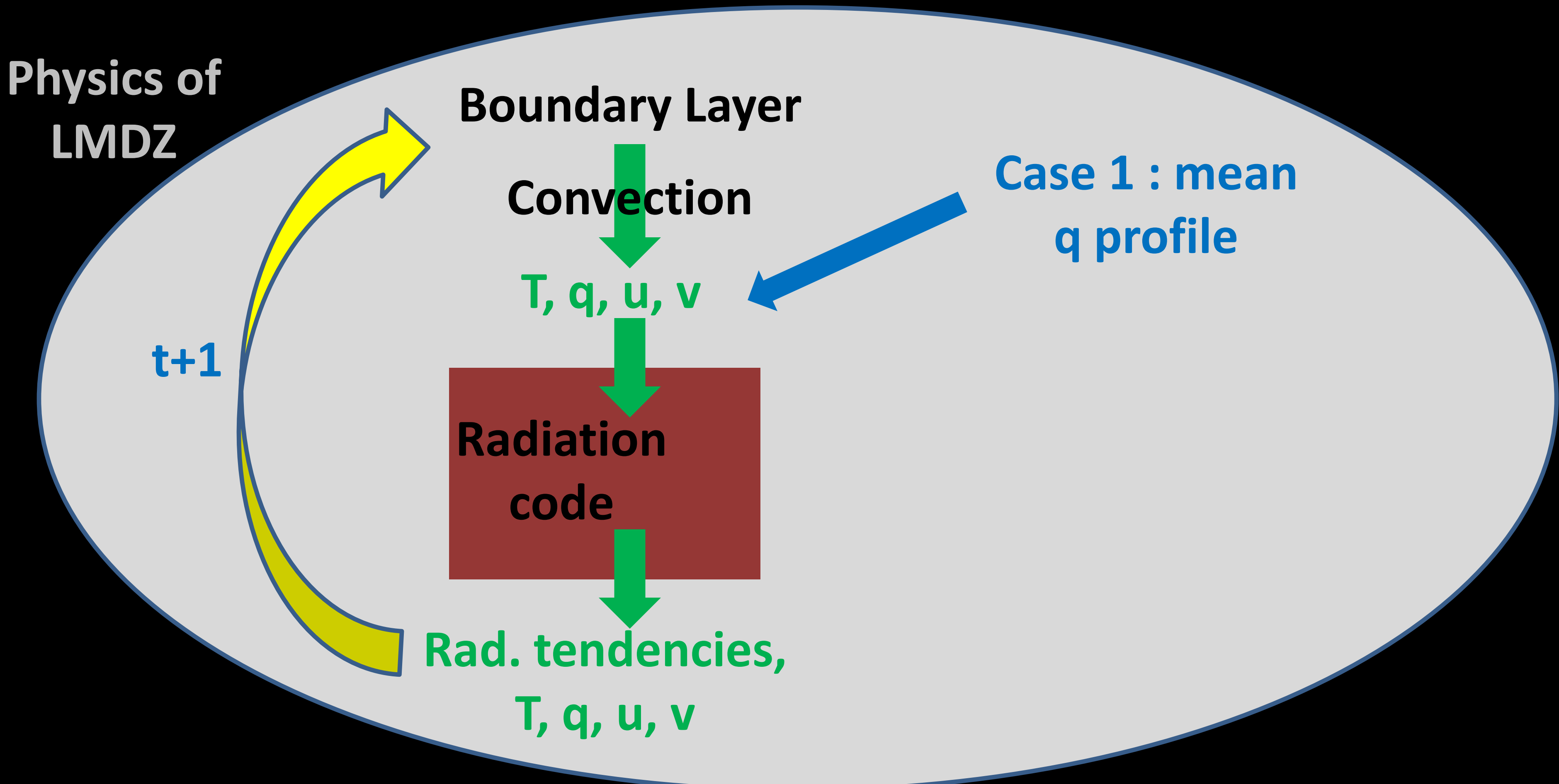
Same without Cloud Radiative Effects



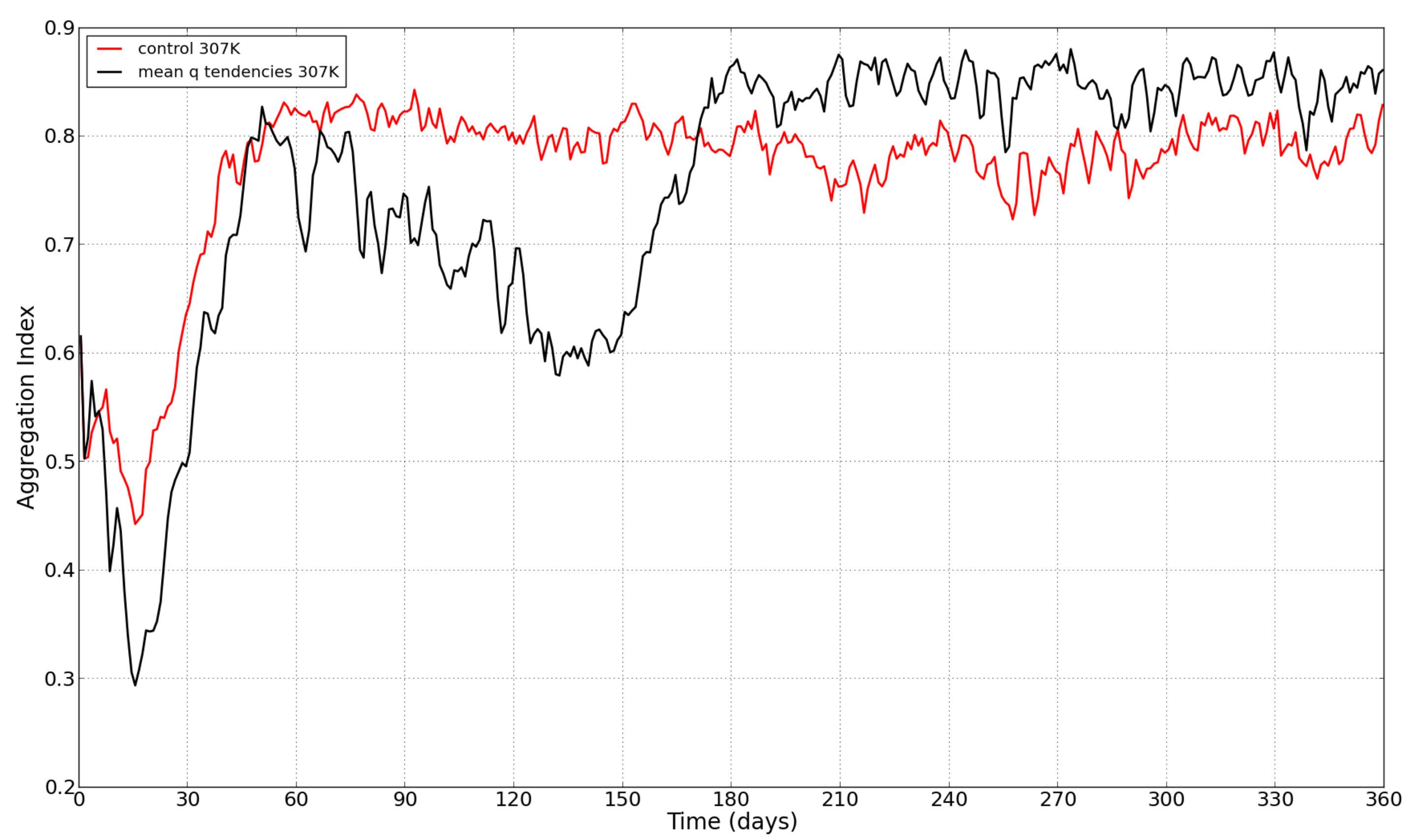
Focus on humidity

Homogeneisation Experiments

Test the role of horizontal humidity gradients

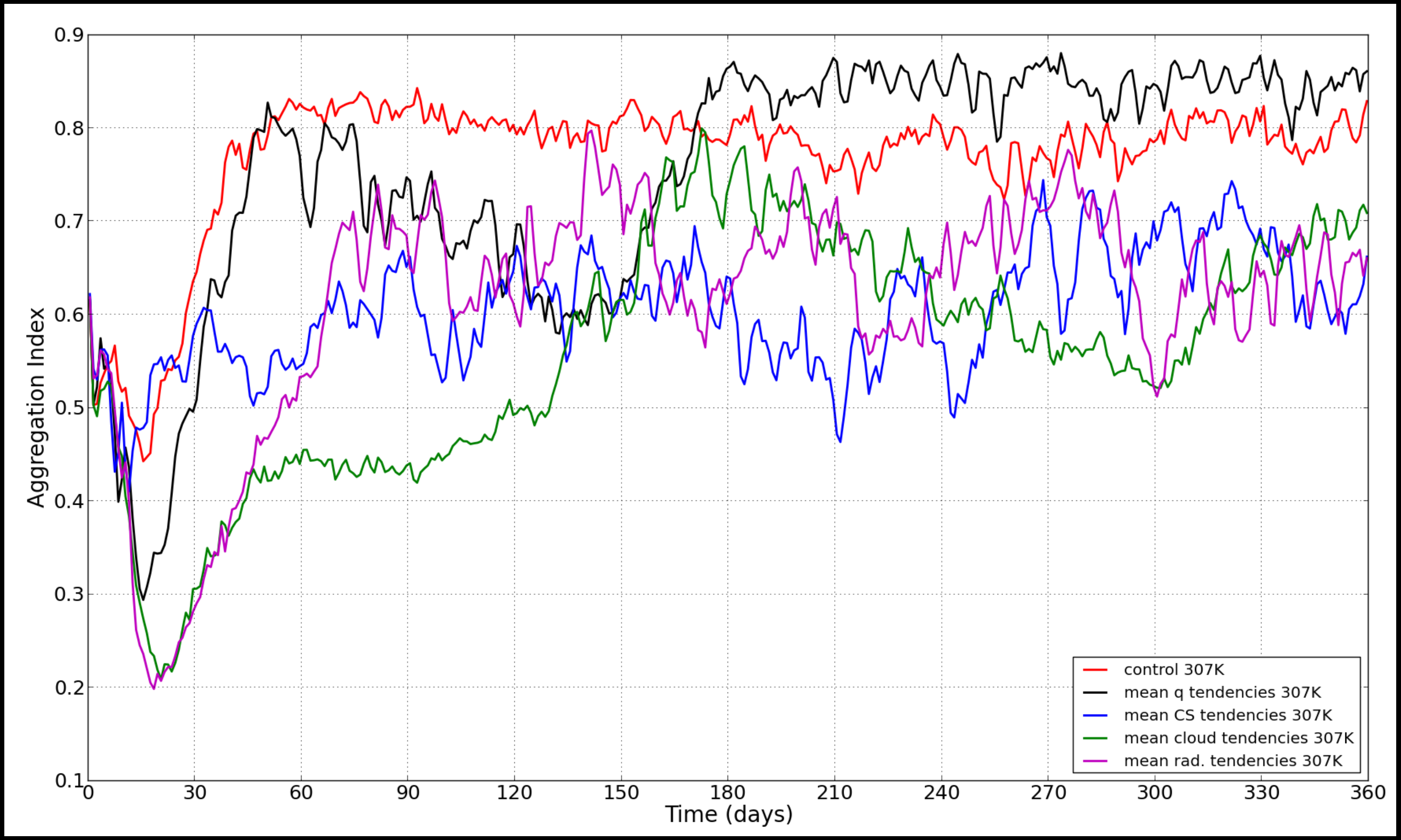


On/Off experiments on humidity



Horizontal humidity gradients : not a fondamental role for initiation

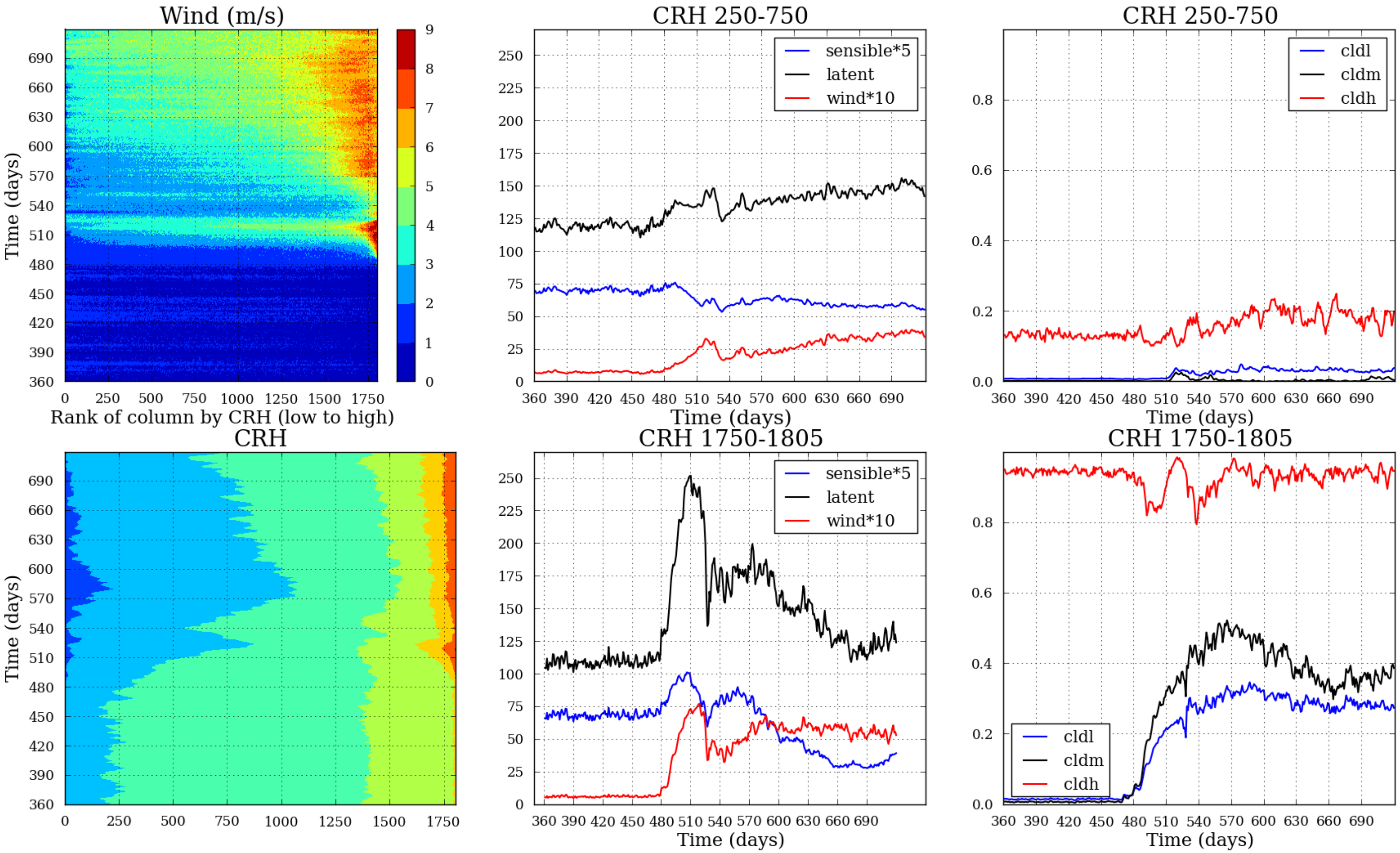
Homogenization experiments on radiative tendencies



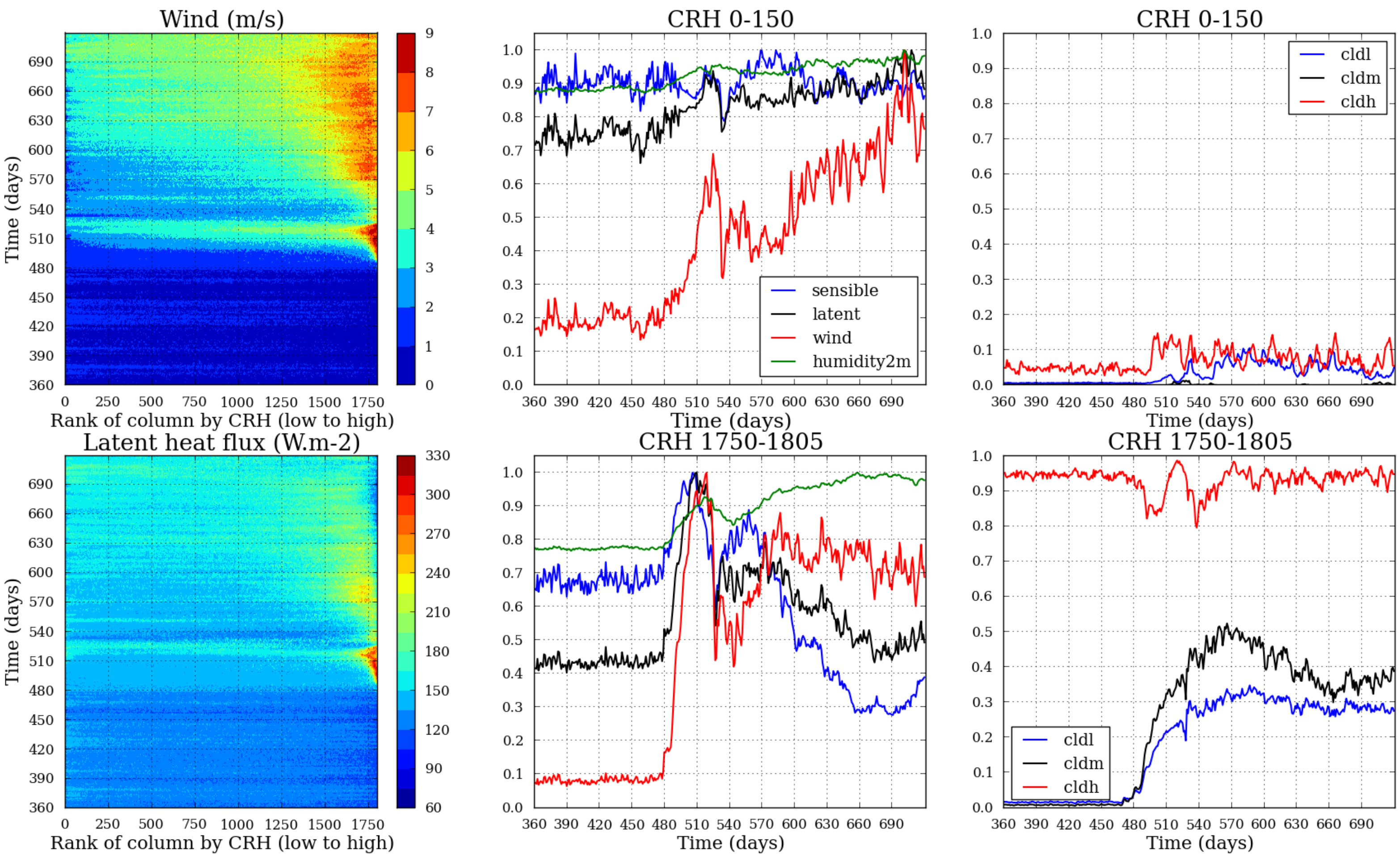
Same equilibrium at AI=0.6

Follow the « cloudy » curve at the beginning + variability like CS

➔ Characteristics of both cloudy and CS parts

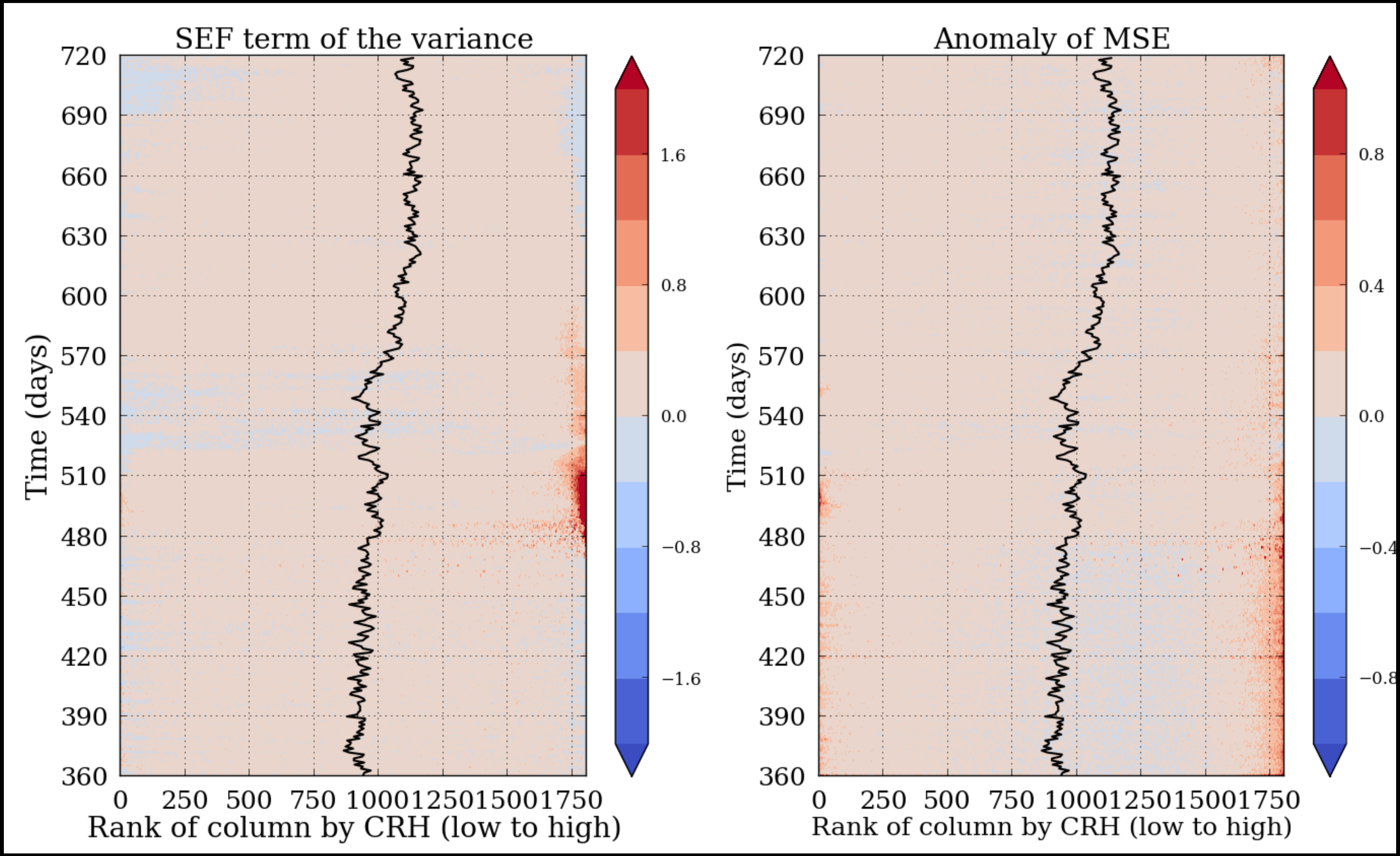


Wind (m/s)
Time (days)
Rank of column by CRH (low to high)
CRH
CRH 250-750
sensible*5
latent
wind*10
Time (days)
CRH 250-750
cldl
cldm
cldh
CRH 1750-1805
sensible*5
latent
wind*10
CRH 1750-1805
cldl
cldm
cldh



Wind (m/s)
Time (days)
Rank of column by CRH (low to high)
CRH 0-150
sensible
latent
wind
humidity2m
Time (days)
CRH 0-150
cldl
cldm
cldh
Time (days)
Latent heat flux (W.m-2)
Time (days)
Rank of column by CRH (low to high)
CRH 1750-1805
Time (days)
CRH 1750-1805
cldl
cldm
cldh
Time (days)

SEF creates the variance of MSE close to initiation



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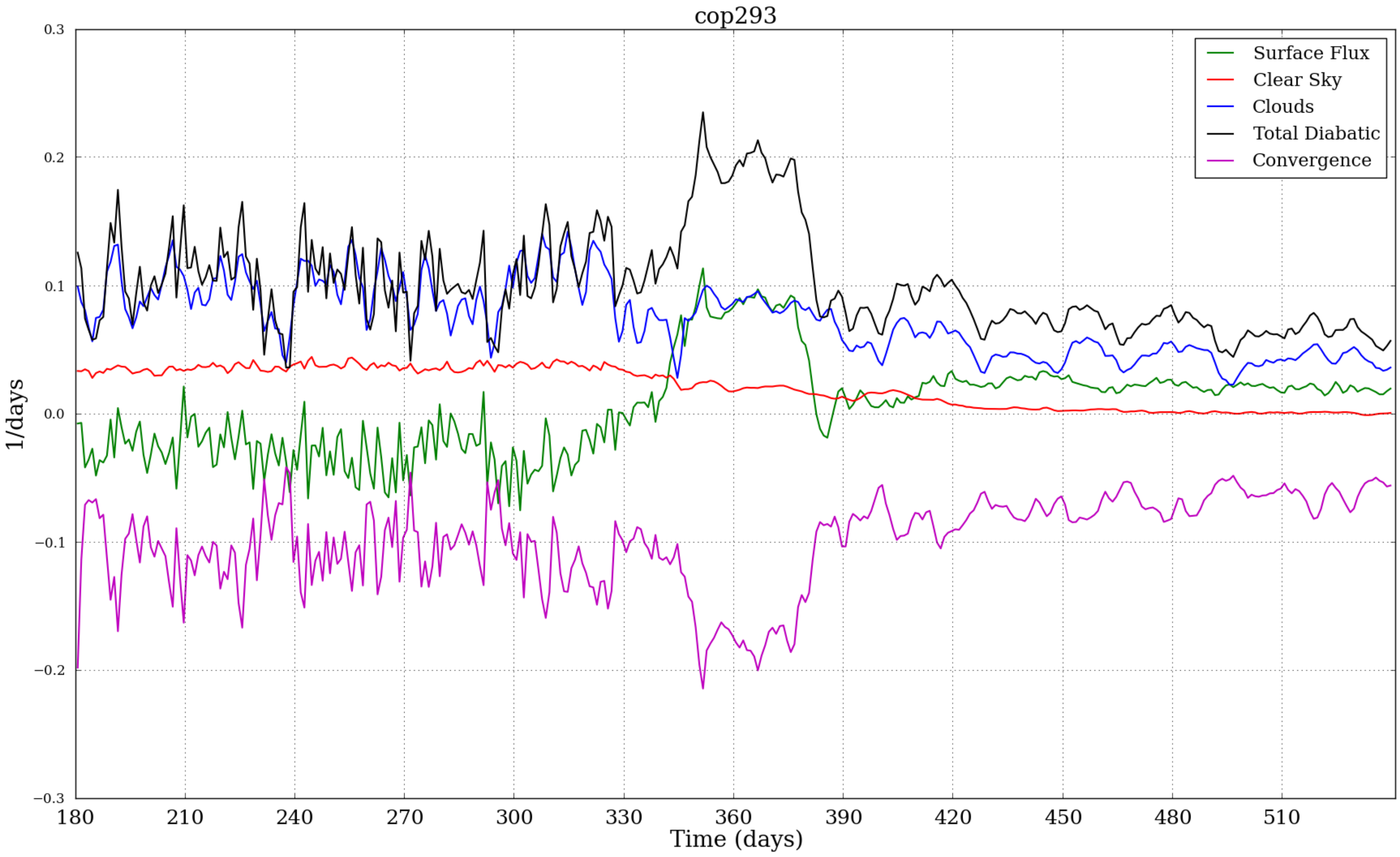

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Surface Flux
Clear Sky
Clouds
Total Diabatic
Convergence
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
1/days
180
210
240
270
300
330
360
390
420
450
480
510
Time (days)

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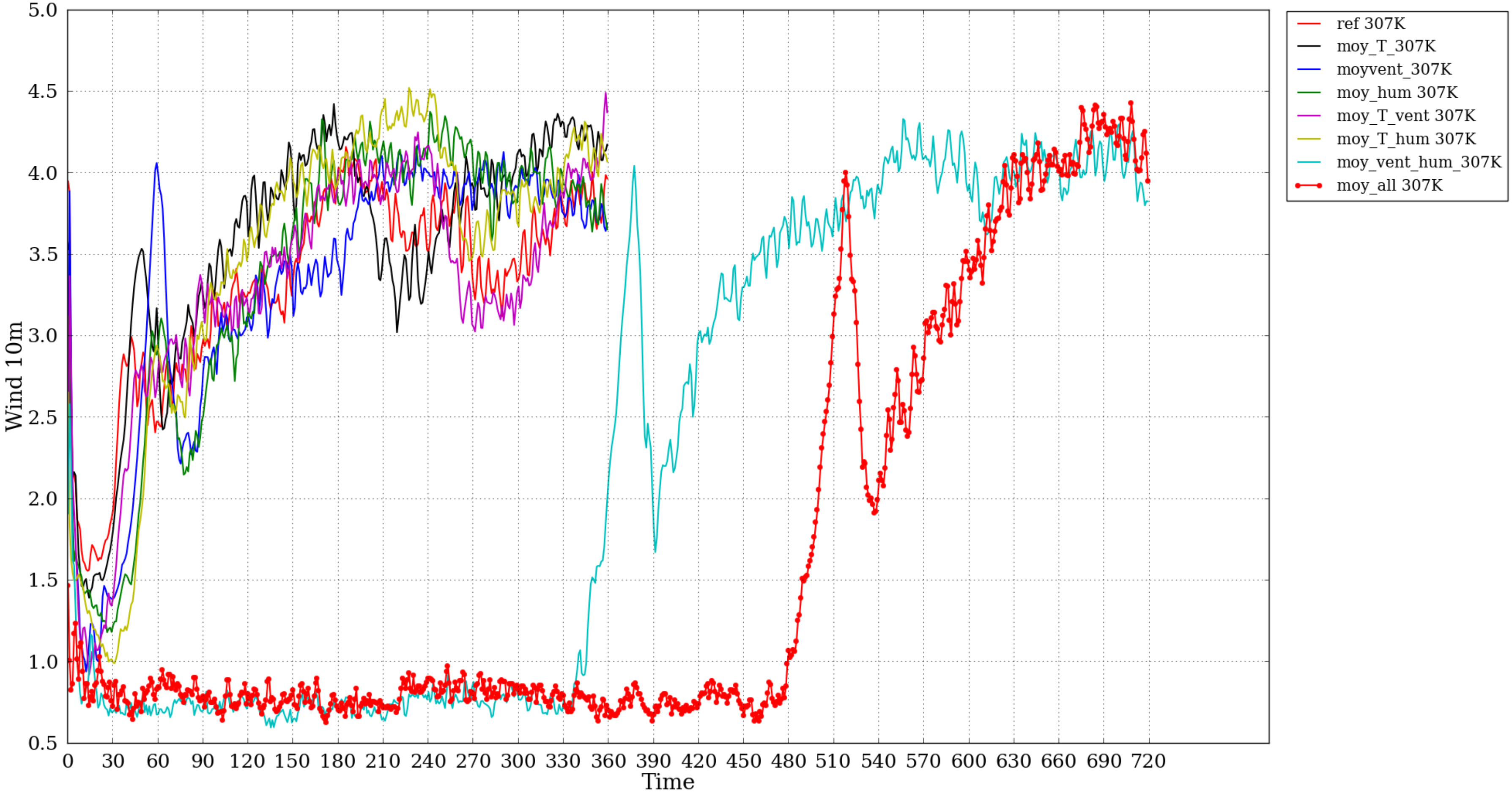


Wind 10m
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720
Time
ref 307K
moy_T_307K
moyvent_307K
moy_hum 307K
moy_T_vent 307K
moy_T_hum 307K
moy_vent_hum_307K
moy_all 307K

Near future

➔ Complete the study on the initiation of self-aggregation (2-3 months) : understand the role of the coupling between wind and humidity
➔ Study of the stationarity of self-aggregation (3-6 months)
➔ Understand why there is no aggregation when no CRE

And also : WTG ? Robustness across GCMs? Across a hierarchy of models?

Write an article about the **processes responsible for RCE instability in LMDZ**
(within 6-9 months)

Implications for LMDZ development

Look at what happens with the cold pools (especially for the initiation which is dependent on the surface fluxes) → dependence on the representation of physical processes

LMDZ6 : look at robustness + role of cold pools (coupling wind-humidity + surface fluxes + test CRM's results about cold pools) + CRE

Information on what is missing or should be better represented to take into account the organization of convection + process study

Role of self-aggregation in the climate

Work on one of the 4 questions of the WCRP Grand Challenge

Different « key issues » :

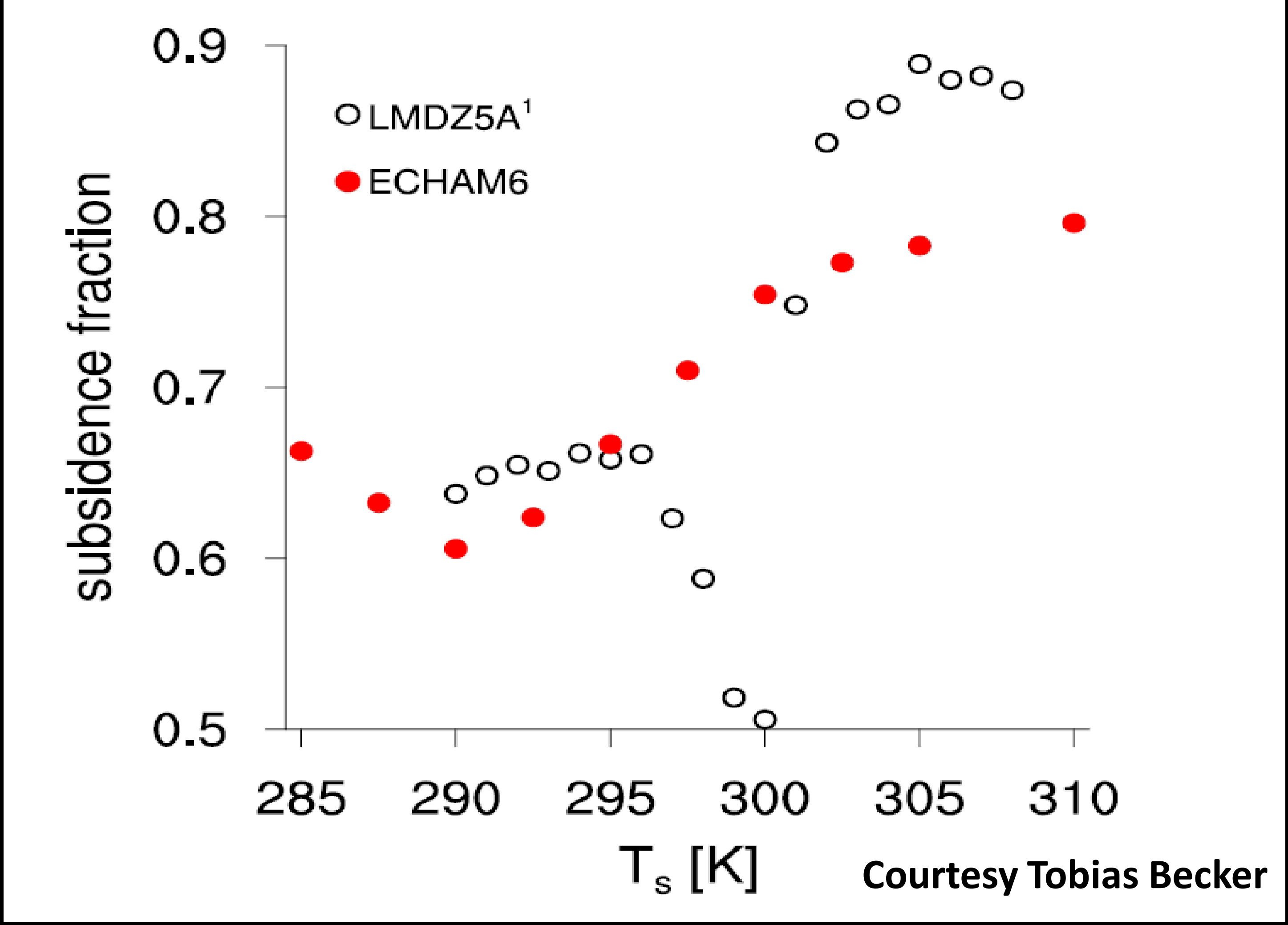
- **ITCZ**
- **Madden-Julian Oscillation**
- **Climate Sensitivity**

Ways to study these issues : **Hierarchy of model configurations**; WTG?

Advantage to work on this before the previous point : we will know if self-aggregation needs to be parametrized in GCMs + very hot topic

Disadvantage : quite long (1 year with an article) ➔ less time to do something else

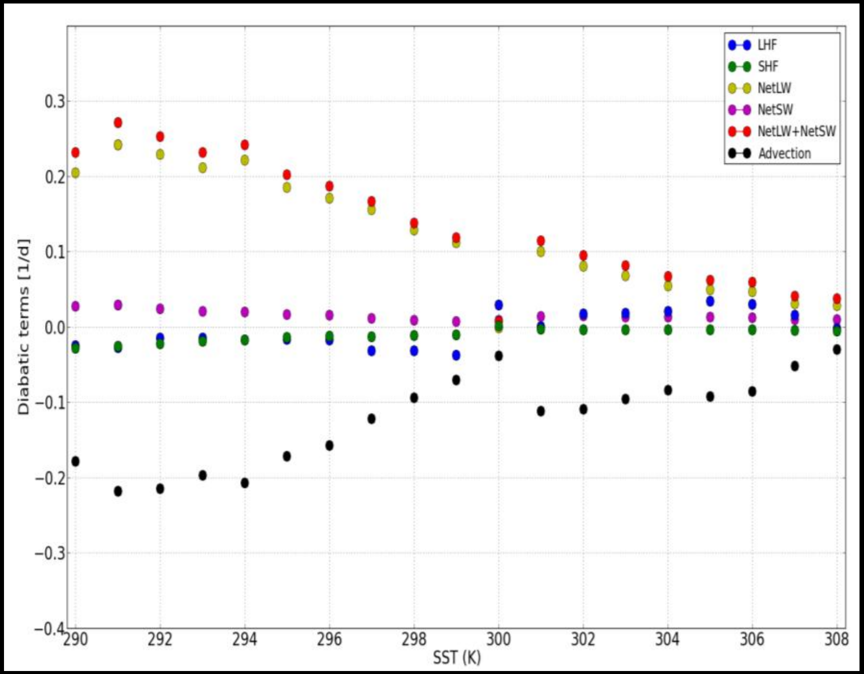
Dependence on SST in ECHAM6

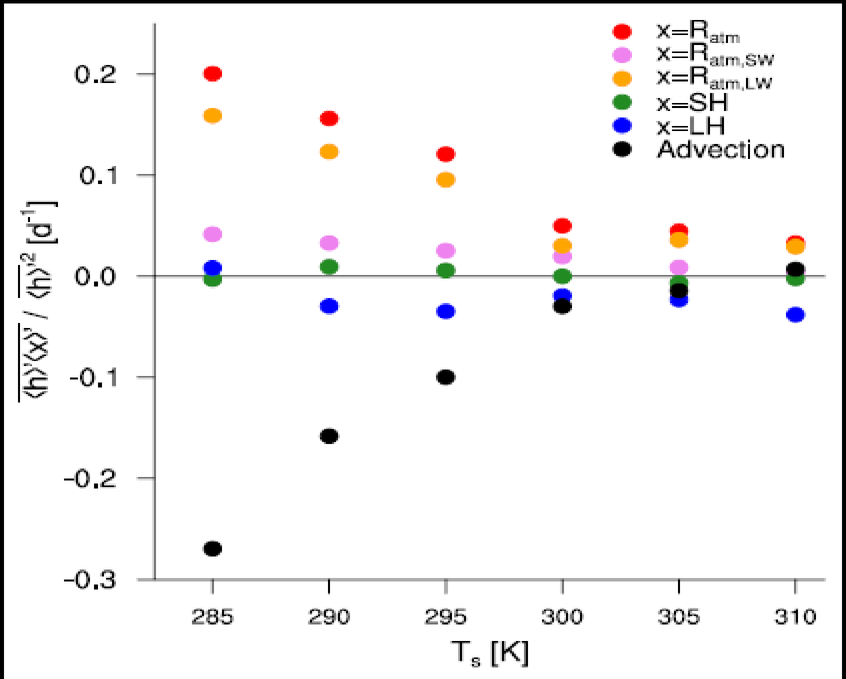


Also different regimes but self-aggregation for a bigger range of SST.
Strange behaviour of the 290K simulation → similar to my 300K simulation ?

Dependence of feedbacks on SST

LMDZ5A (left) and ECHAM6 (right) in RCE with fixed SST





- Robustness of the trends but role of LH totally different
- For high SSTs, MSE energy variance is more equally distributed among LW, SW, surface fluxes ➔ the processes governing self-aggregation may be SST-dependent.

Explain the different forms of self-aggregation ?