ETH Contributions to VI-ACI (M2/M3)

Ulrike Lohmann

ETH Zurich
Institute for Atmospheric
and Climate Science

Karlsruhe,
14.5.2007

Contributions from
Corinna Hoose and Peter
Spichtinger

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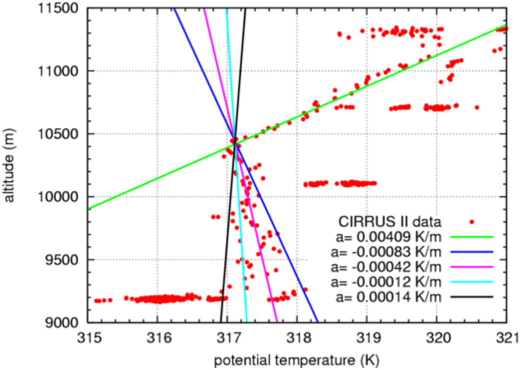
Internal Dynamics in Cirrus

Measurements from the CIRRUS II Campaign: Up to 50-80 ice crystals cm^{-3}, large-scale motion: $w = 3cm/s$



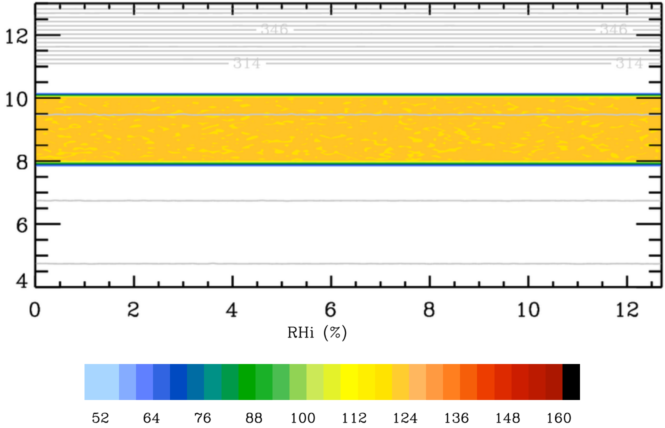
These cirrus probably formed due to strong wind shear and the presence of neutral layers

Internal Dynamics in Cirrus

EULAG 2D simulation with bulk ice microphysics

$w = 5cm/s$, stable stratification,

t= 000 min



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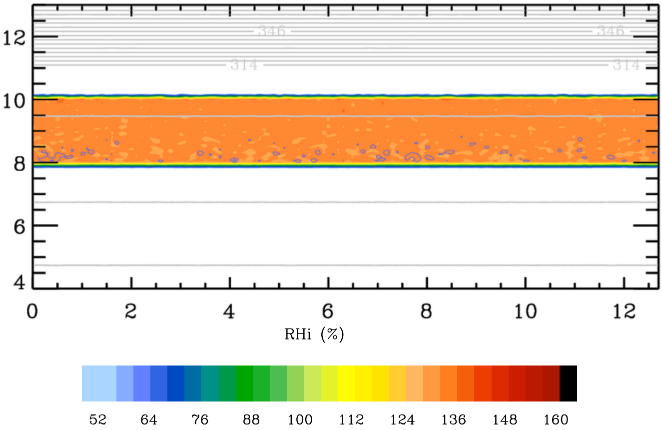
Internal Dynamics in Cirrus

$w = 5cm/s$, stable stratification,

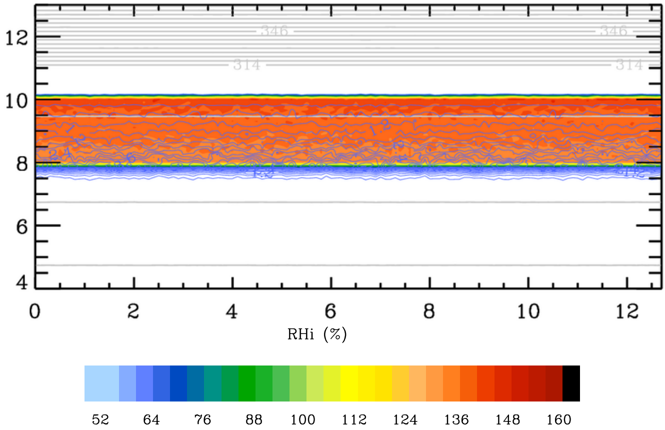
t= 030 min



Internal Dynamics in Cirrus

$w = 5cm/s$, stable stratification,

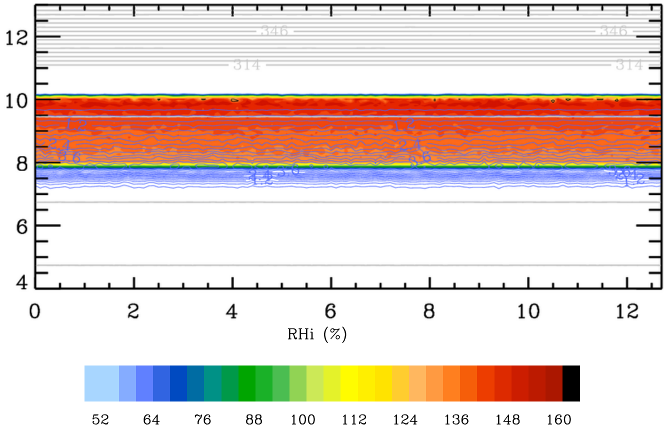
t= 060 min



Internal Dynamics in Cirrus

$w = 5 cm/s$, stable stratification,

t= 090 min



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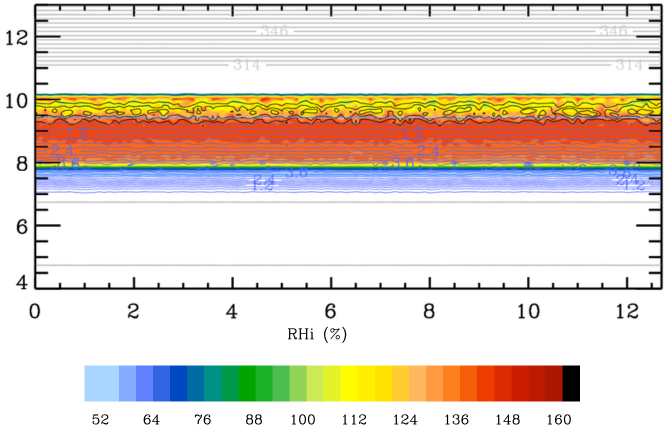
Internal Dynamics in Cirrus

$w = 5cm/s$, stable stratification,

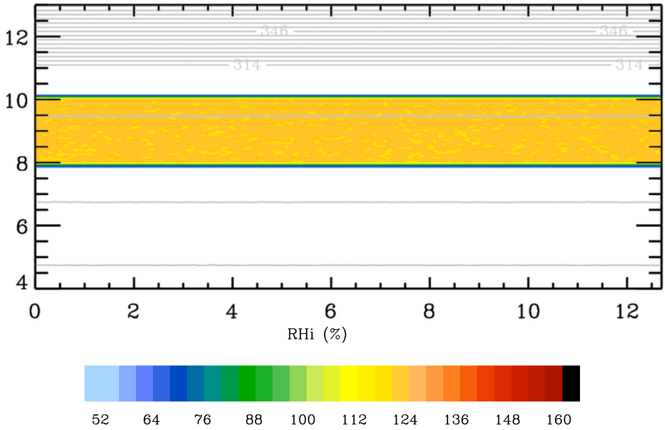
t= 120 min



Internal Dynamics in Cirrus

$w = 5cm/s$, neutral stratification

t=000min



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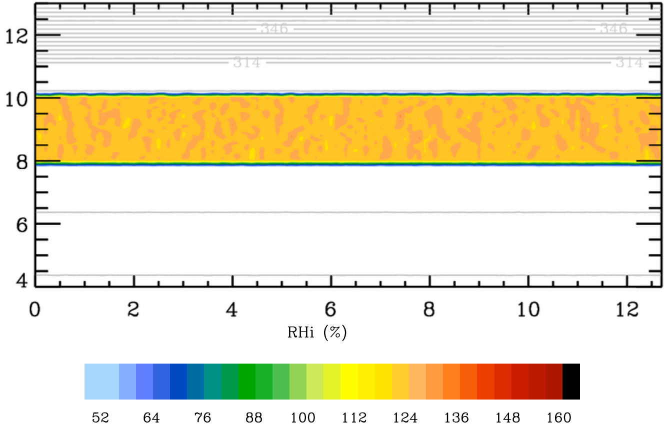
Internal Dynamics in Cirrus

$w = 5cm/s$, neutral stratification

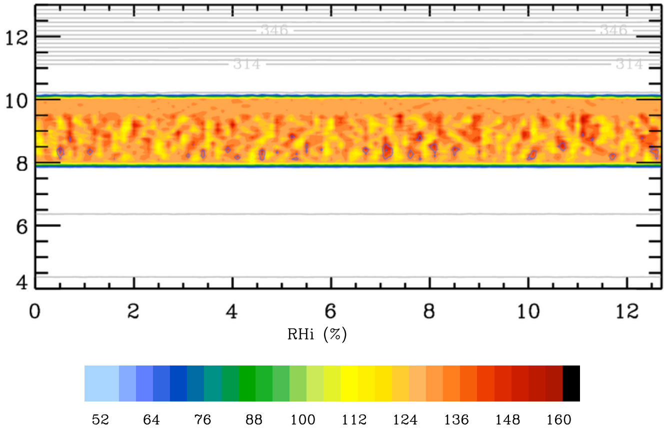
t=010min



Internal Dynamics in Cirrus

$w = 5cm/s$, neutral stratification

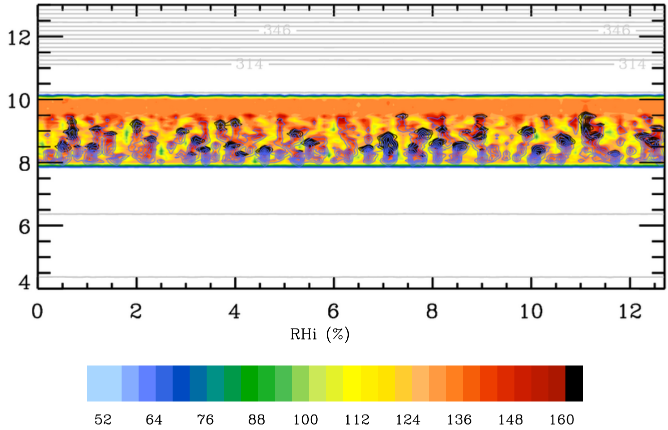
t=020min



Internal Dynamics in Cirrus

$w = 5cm/s$, neutral stratification

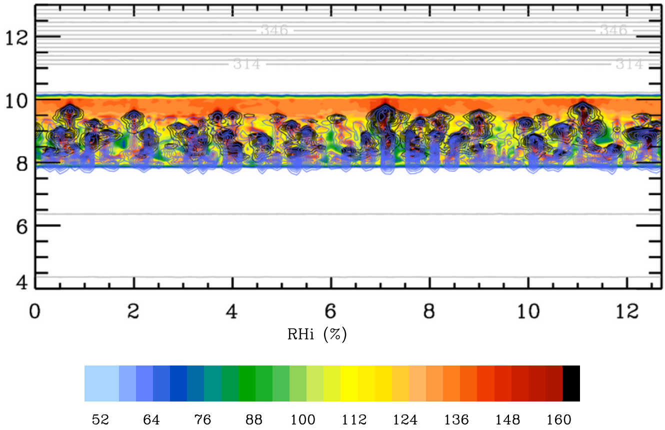
t=030min



Internal Dynamics in Cirrus

$w = 5cm/s$, neutral stratification

t=040min



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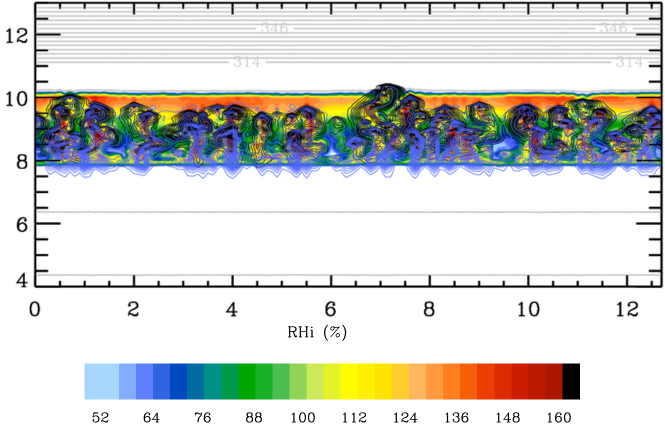
Internal Dynamics in Cirrus

$w = 5cm/s$, neutral stratification

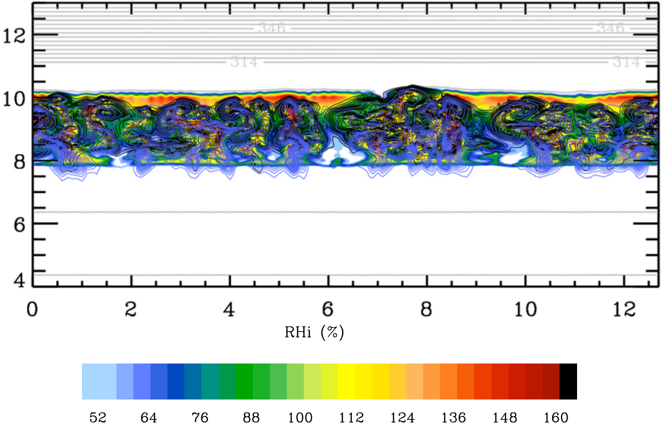
t=050min



Internal Dynamics in Cirrus

$w = 5cm/s$, neutral stratification

t=060min



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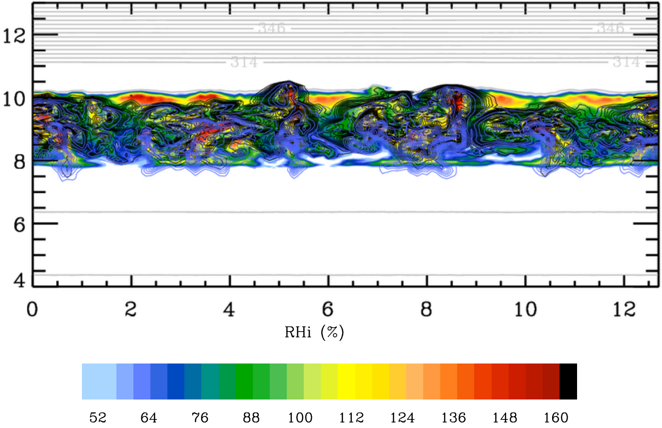
Internal Dynamics in Cirrus

$w = 5cm/s$, neutral stratification

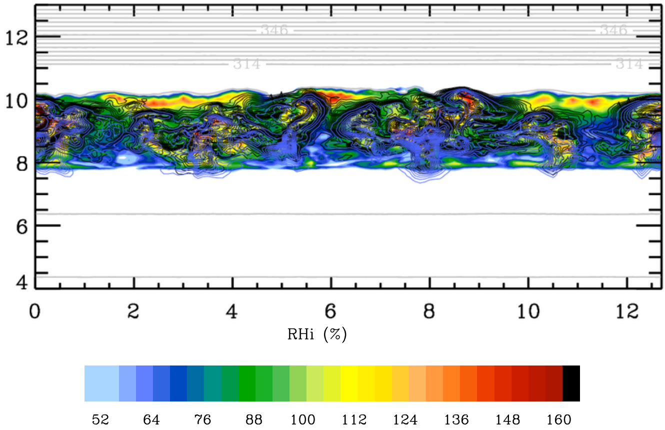
t=070min



Internal Dynamics in Cirrus

$w = 5 cm/s$, neutral stratification

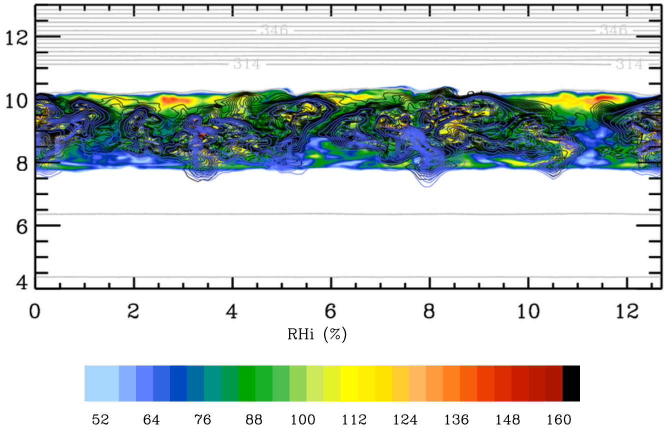
t=080min



Internal Dynamics in Cirrus

$w = 5cm/s$, neutral stratification

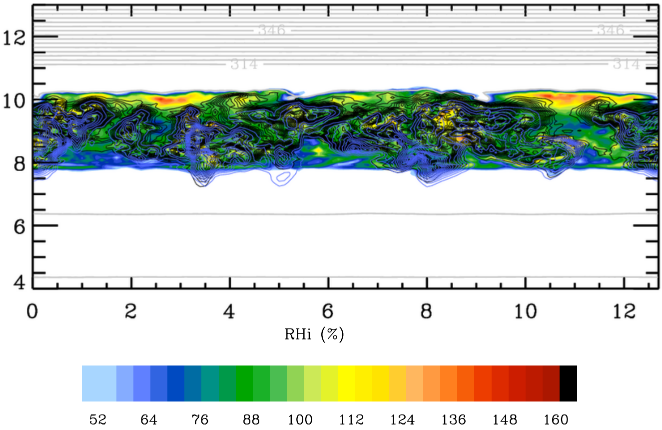
t=090min



Internal Dynamics in Cirrus

$w = 5cm/s$, neutral stratification

t=100min



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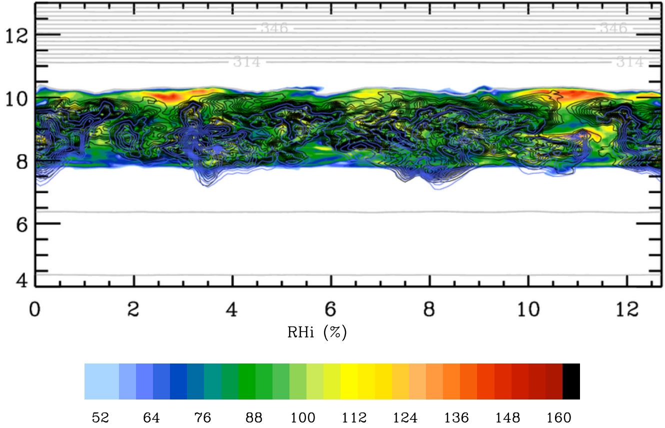
Internal Dynamics in Cirrus

$w = 5cm/s$, neutral stratification

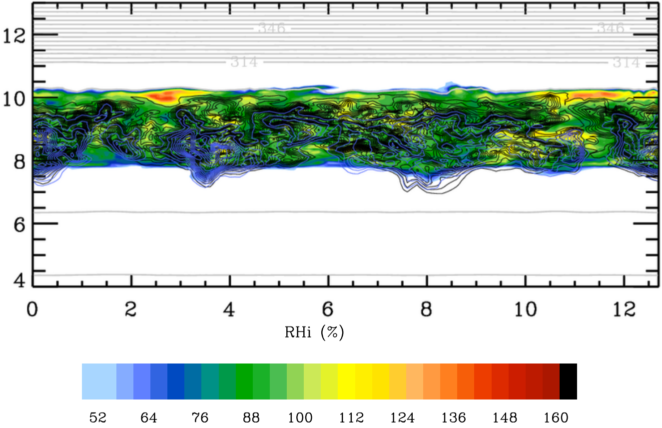
t=110min



Internal Dynamics in Cirrus

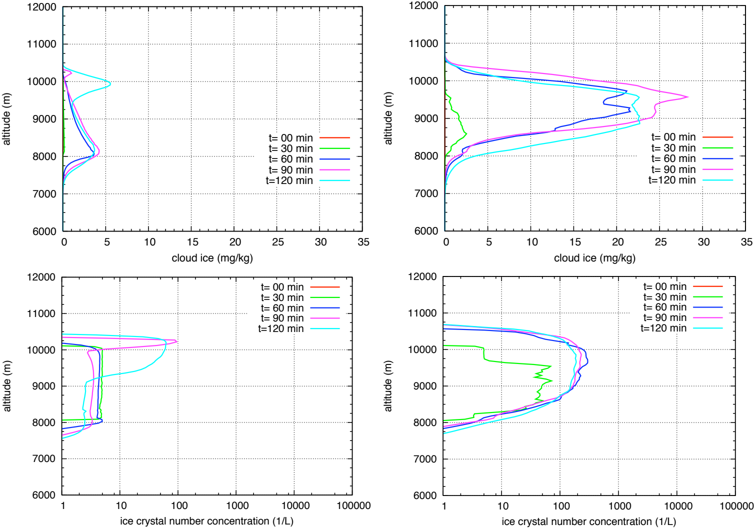
$w = 5cm/s$, neutral stratification

t=120min



Internal Dynamics in Cirrus

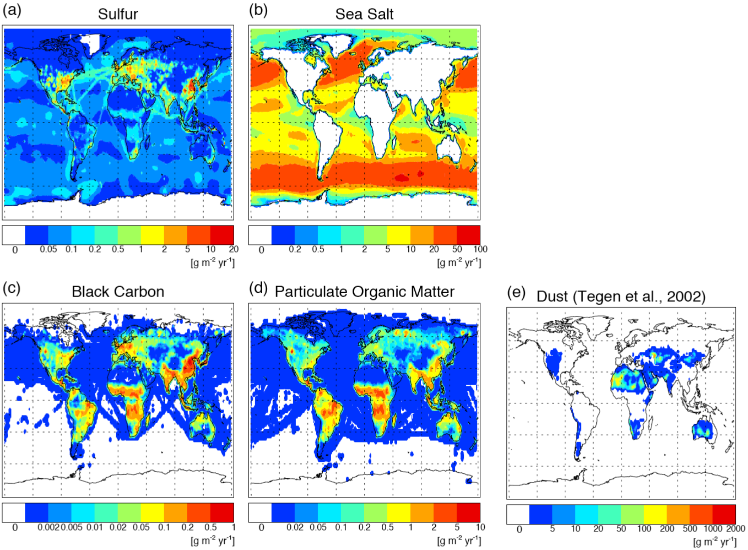
Comparison: Large difference due to internal dynamics



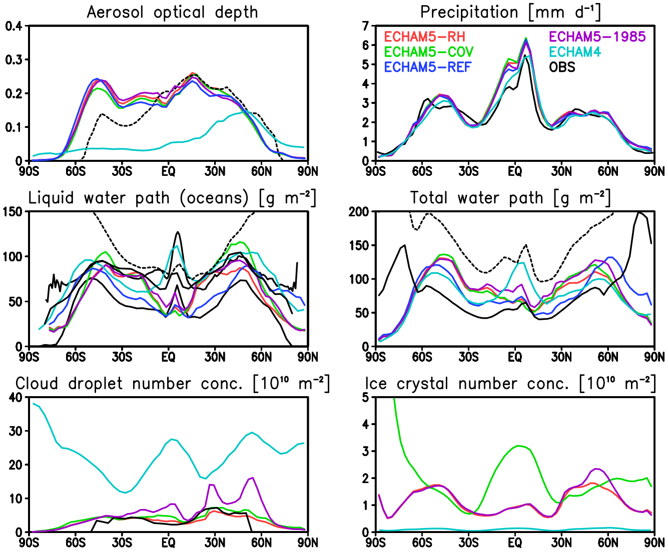
Model set-up in ECHAM5 [Lohmann et al., ACPD, 2007]

- ECHAM5 global climate model (Roeckner et al., 2003)
- 5-year simulations in T42 resolution (2.8°x 2.8°), 19 levels
- 2-moment aerosol scheme ECHAM5-HAM (Stier et al., 2005)
- 4 pairs of simulations:
  - ECHAM5-RH: Using a relative humidity based cloud cover scheme (Sundqvist et al., 1989)
  - ECHAM5-COV: Using a statistical cloud cover scheme (Tompkins, 2002)
  - ECHAM5-1985: Using the 1985 aerosol emissions (Liousse et al., 1996) instead of 2000 (Dentener et al., 2006)
  - ECHAM5-CIR: As ECHAM5-RH with cirrus scheme (preliminary!)
  - ECHAM4: As ECHAM5-1985 with cirrus scheme
  - Each simulation pair is run with present-day and pre-industrial (1750) aerosol emissions

Global aerosol sources [Stier et al., ACP, 2005]



Climate model validation



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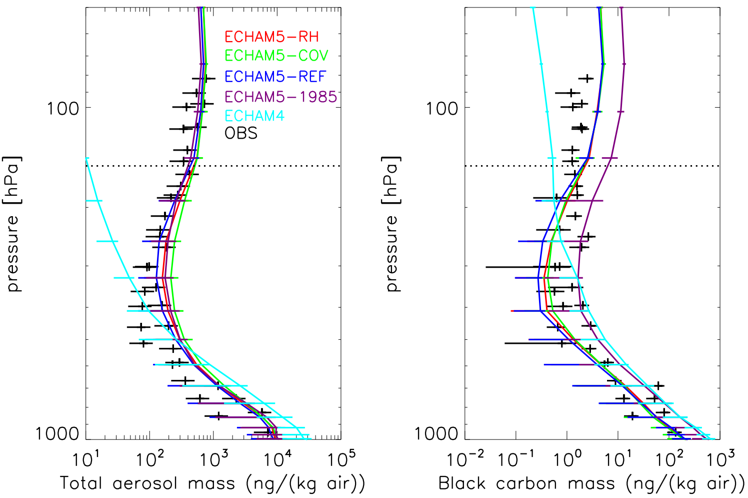
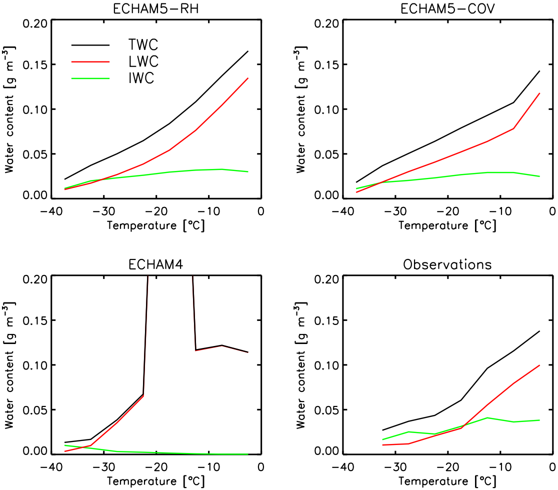
Vertical distribution of black carbon and total aerosol mass in Texas [Obs. from Schwarz et al., JGR, 2006]



Liquid (LWC), ice (IWC) and total water content (TWC) in mixed-phase clouds [Observations from Korolev et al., QJ, 2003]



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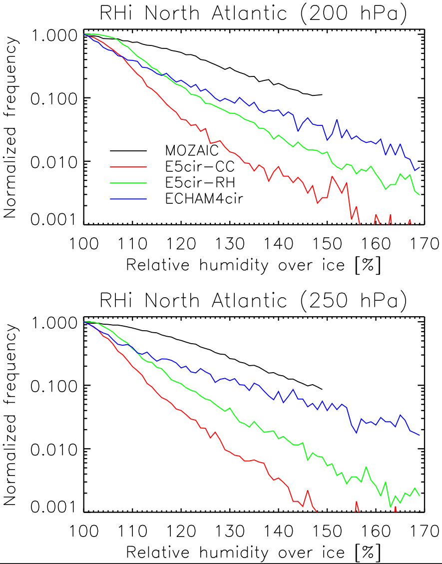
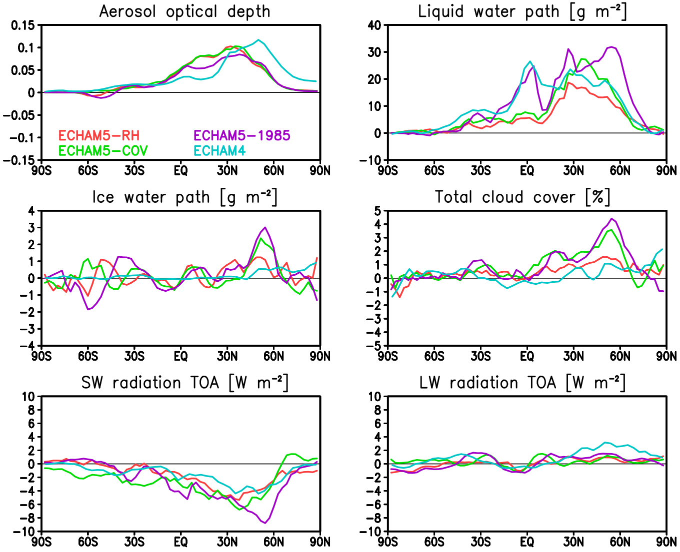
Frequency distribution of supersaturation with respect to ice

[Observations from Gierens et al., 1999]



Annual zonal mean changes present - 1750



Global annual mean changes present-day - 1750

Simulation	EC5 -RH	EC5 -COV	EC5 -1985	EC5 -CIR	EC4
Aerosol optical depth	0.04	0.042	0.035	0.04	0.037
Liquid water path, g m^{-2}	6.5	9.2	13.6	6.4	12.7
Ice water path, g m^{-2}	0.18	0.18	0.30	0.14	0.10
N_d, 10^{10} m^{-2}	1.0	1.4	3.6	1.0	4.1
N_i, 10^{10} m^{-2}	0.06	0.04	0.13	0.01	0.03
Cloud cover, %	0.5	1.0	1.0	0.3	0.1
Precipitation, mm d^{-1}	-0.004	-0.011	-0.022	-0.01	-0.05
SW radiation, W m^{-2}	-2.0	-3.2	-3.1	-1.8	-1.8
LW radiation, W m^{-2}	0.2	0.3	0.4	-0.1	0.7
Net radiation, W m^{-2}	-1.8	-2.9	-2.8	-1.9	-1.0

Glaciation indirect aerosol effect

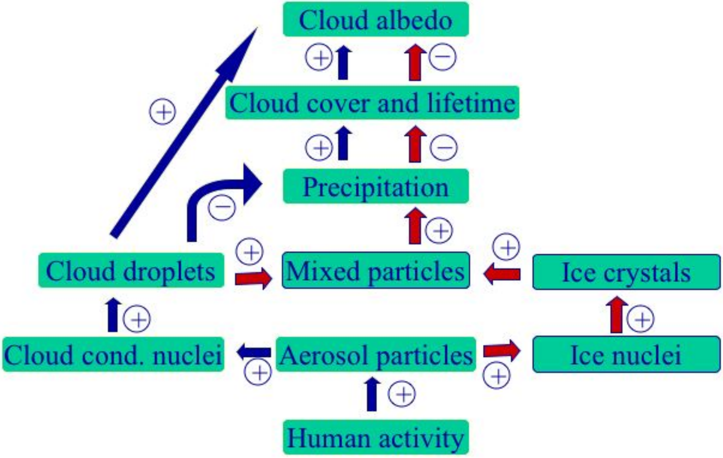
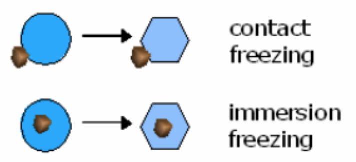
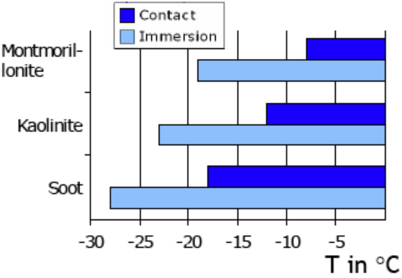


Figure: Lohmann, GRL, 2002

Heterogeneous freezing

- Mixed-phase clouds (-38°C<T<0°C)
- In ECHAM5-HAM: only contact and immersion freezing, dust and black carbon





Median freezing temperatures for different IN from lab experiments. Drop radii 250-350 μm. Adapted from *Diehl et al. (2005)*.

- IN efficiencies depend on material and drop volume

Number concentration of different aerosols

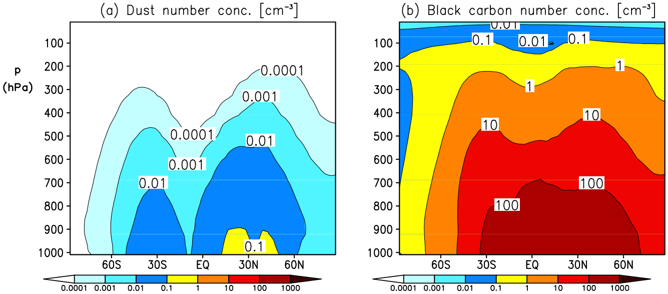


Figure: Annual zonal mean latitude-height cross-sections

Annual zonal mean indirect aerosol effect

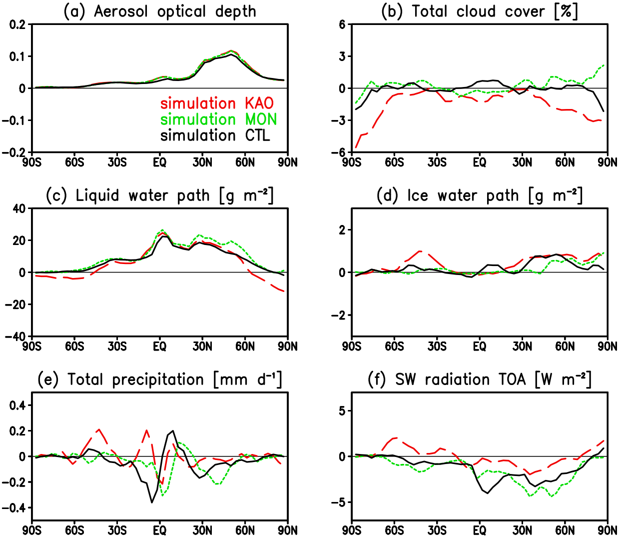
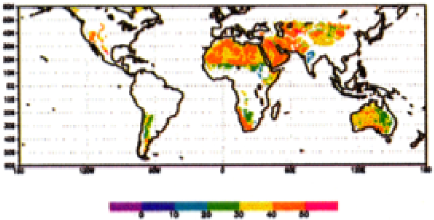
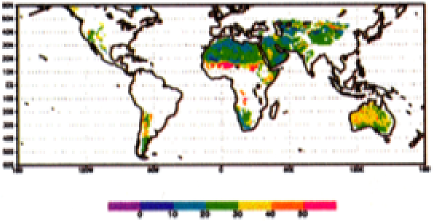


Table: Global annual mean changes ± interannual standard deviations of liquid water path (ΔLWP, g m^{-2}), ice water path (ΔIWP, g m^{-2}), total cloud cover (ΔTCC, %), precipitation (ΔPR, mm d^{-1}), shortwave (ΔF_{SW}, W m^{-2}), longwave (ΔF_{LW}, W m^{-2}) and net TOA radiation (ΔF_{net}, W m^{-2}) between pre-industrial and present-day in ECHAM4 [Lohmann and Diehl, JAS, 2006].

Simulation	CTL	KAO	MON
ΔLWP	10.5±0.7	9.8±0.6	12.7±0.4
ΔIWP	0.2±0.1	0.4±0.04	0.1±0.03
ΔTCC	0.1±0.4	-1.0±0.3	0.1±0.2
ΔPR	-0.05±0.01	0.005±0.01	-0.05±0.01
ΔF_{SW}	-1.6±0.4	-0.2±0.2	-1.8±0.1
ΔF_{LW}	0.6±0.3	-1.8±0.2	0.7±0.2
ΔF_{net}	-1.0±0.3	-2.0±0.2	-1.0±0.2

Differentiate illite and kaolinite [Claquin, JGR, 1999]





Next step: Allow different mineral dusts for freezing

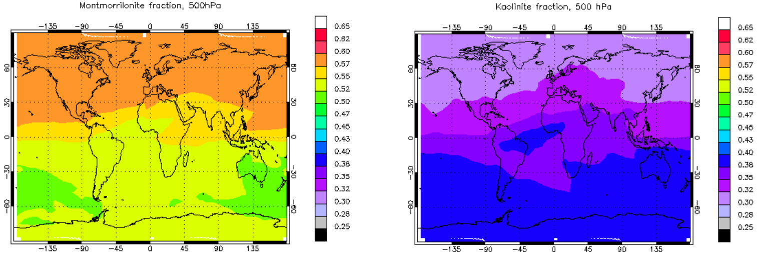
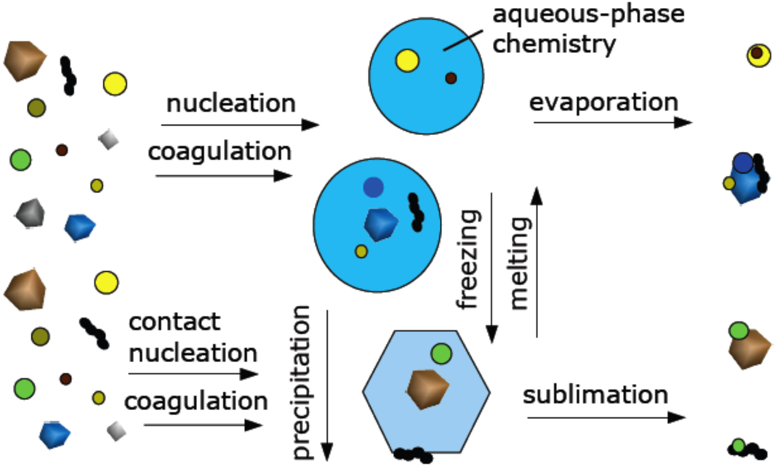


Figure: Ina Tegen/Corinna Hoose, pers. comm.

Conclusions and outlook

- Cloud modelling: Temperature fluctuations in neutral layers induce vertical updrafts; ice crystals form; due to latent heat release small convective cells occur
- Global results: The indirect aerosol effect in ECHAM5 with a relative humidity based cloud cover scheme is similar as in ECHAM4 ($\sim$ -1.8 W m^{-2}). It is larger when either a statistical cloud cover scheme or a different aerosol emission inventory are employed.
- The importance of the glaciation indirect effect is currently being tested in ECHAM5 (work by Corinna Hoose)
- Cloud processing is currently being developed for ECHAM5 (work by Corinna Hoose)

Aerosol processing



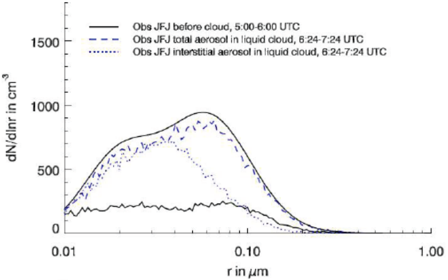
ECHAM5-HAM with aerosol processing

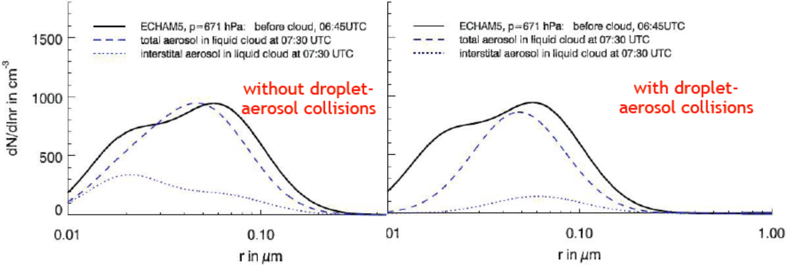
Coupling to cloud microphysics:

- uptake by nucleation and collisions
- transfer droplet-crystal: freezing (and melting)
- upon droplet/crystal evaporation: release as one bigger particle, attribution to correct interstitial mode

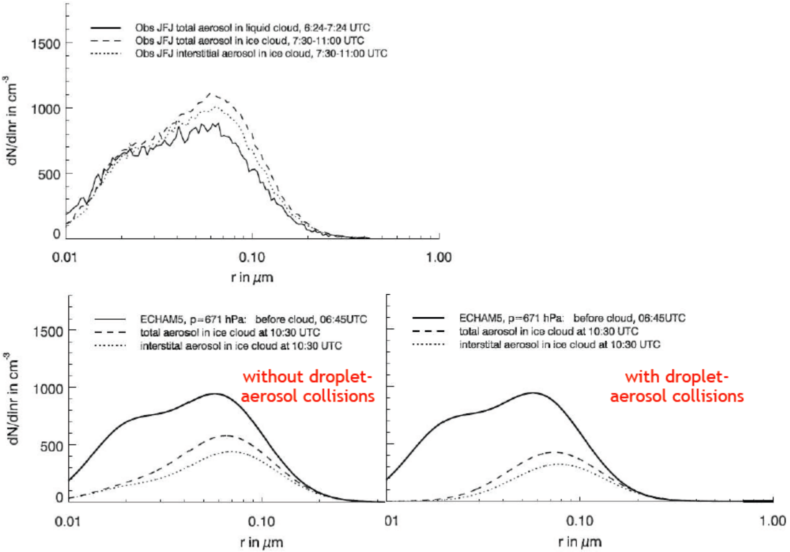
	Median r[μm]	Internally mixed	Externally mixed
Nucleation	r<0.005	N_1, M_1^{SU}	
Aitken	0.005<r<0.05	N_2, M_2^{SU}, M_2^{BC}, M_2^{POM}	N_5, M_5^{BC}, M_5^{POM}
Accumulation	0.05<r<0.5	N_3, M_3^{SU}, M_3^{BC}, M_3^{POM}, M_3^{SS}, M_3^{DU}	N_6, M_6^{DU}
Coarse	0.5<r	N_4, M_4^{SU}, M_4^{BC}, M_4^{POM}, M_4^{SS}, M_4^{DU}	N_7, M_7^{DU}
in-droplet		N_8, M_8^{SU}, M_8^{BC}, M_8^{POM}, M_8^{SS}, M_8^{DU}	
in-crystal		N_9, M_9^{SU}, M_9^{BC}, M_9^{POM}, M_9^{SS}, M_9^{DU}	

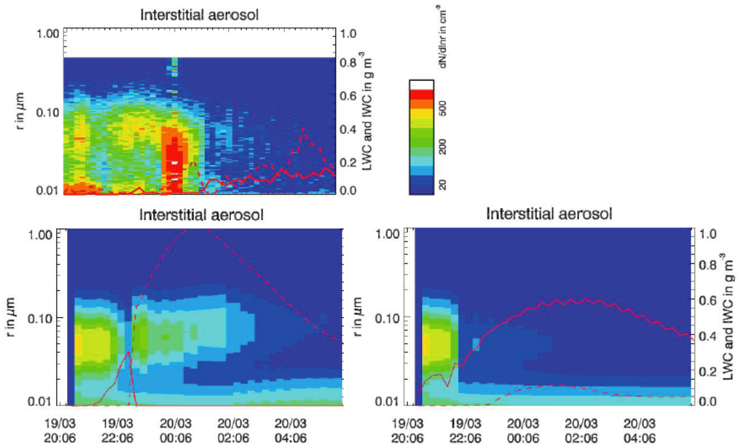
Size distributions in liquid cloud





Size distributions in ice cloud





Standard version: first liquid, then complete glaciation

modified:

- increase RH
- allow simultaneous deposition & condensation
- switch off BF-process in this case

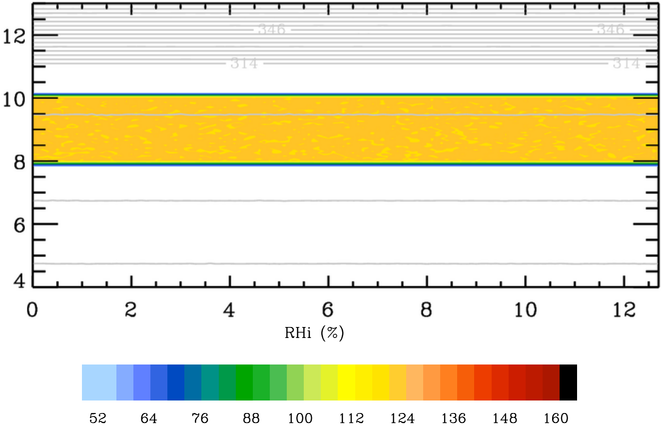
Sensitivity Simulations [Lohmann and Diehl, JAS, 2006]

- 10 year simulations with ECHAM4 in T30 horizontal resolution with 19 vertical levels after 3 months spin-up
- Double moment cloud microphysics scheme
- Dust and soot act as contact and immersion nuclei

Simulation	Description
MON	Assuming dust to be composed of montmorillonite (better freezing nuclei)
KAO	Assuming dust to be composed of kaolinite (worse freezing nuclei)
CTL	Reference simulation, in which both contact and immersion freezing are independent of the chemical composition of the ice nuclei

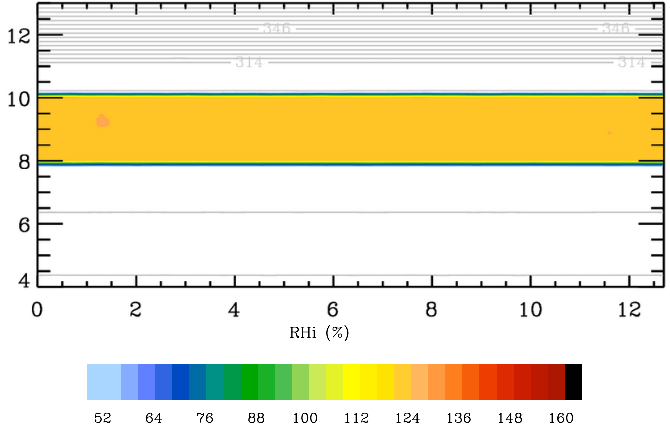
Internal Dynamics in Cirrus

t=000min



Internal Dynamics in Cirrus

t=010min



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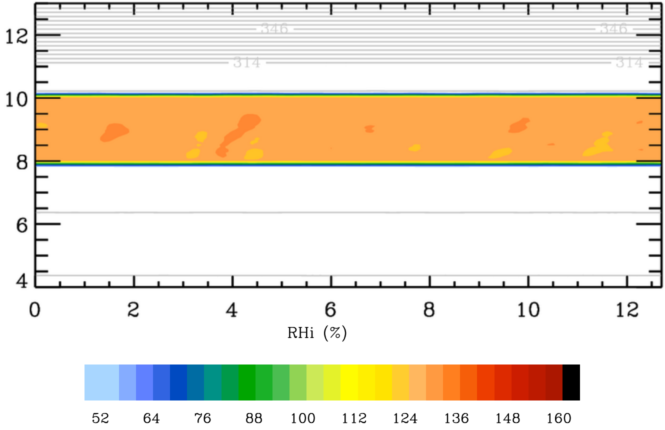
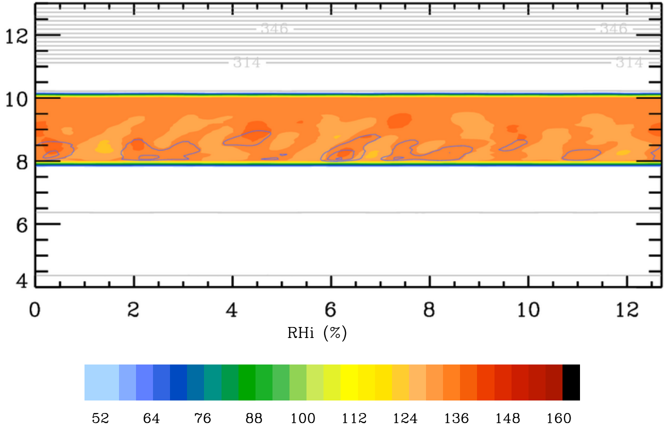
Internal Dynamics in Cirrus

t=020min



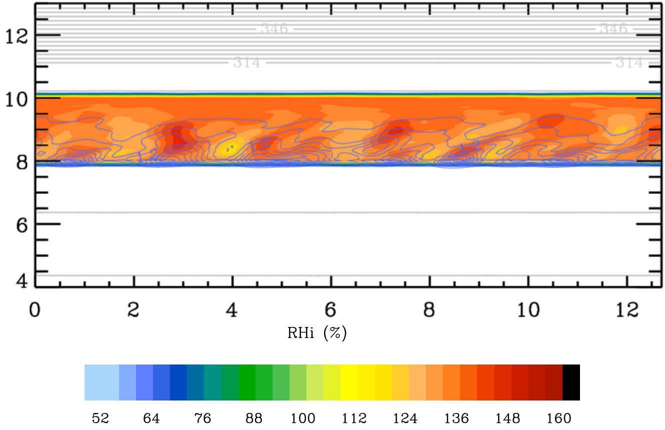
Internal Dynamics in Cirrus

t=030min



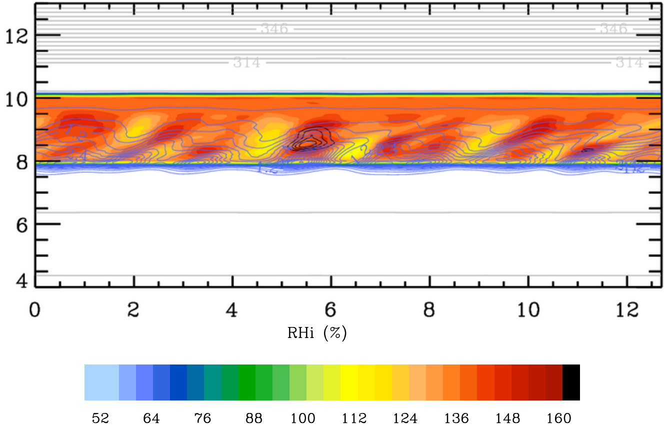
Internal Dynamics in Cirrus

t=040min



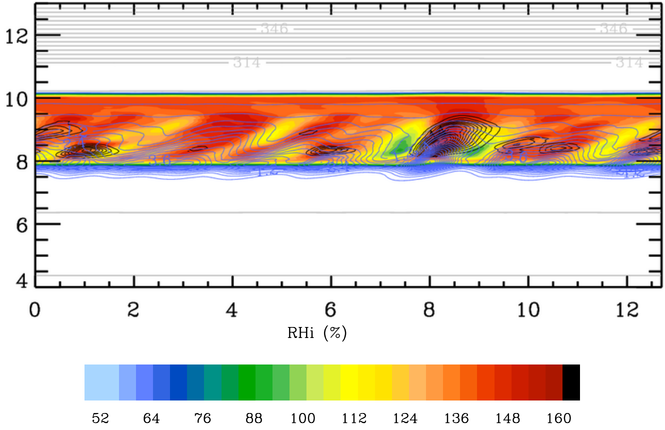
Internal Dynamics in Cirrus

t=050min



Internal Dynamics in Cirrus

t=060min



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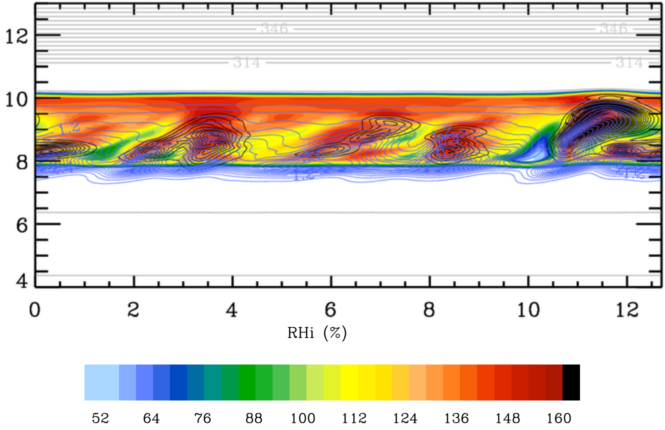
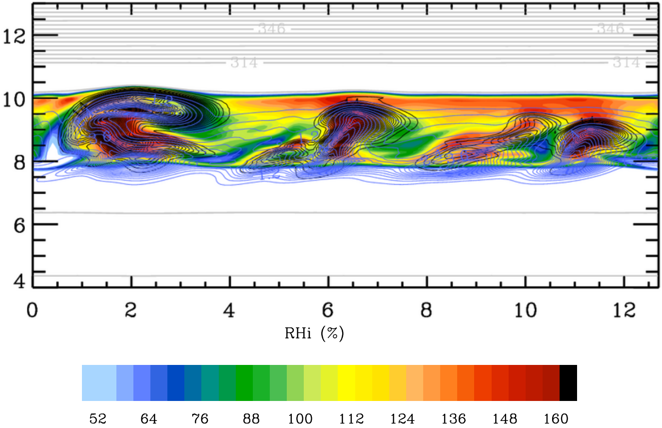
Internal Dynamics in Cirrus

t=070min



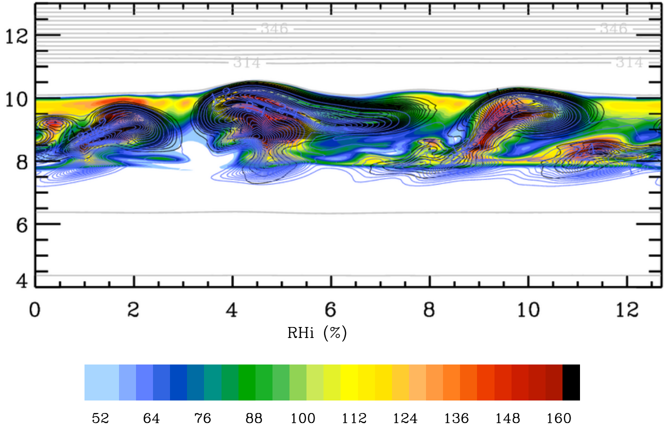
Internal Dynamics in Cirrus

t=080min



Internal Dynamics in Cirrus

t=090min



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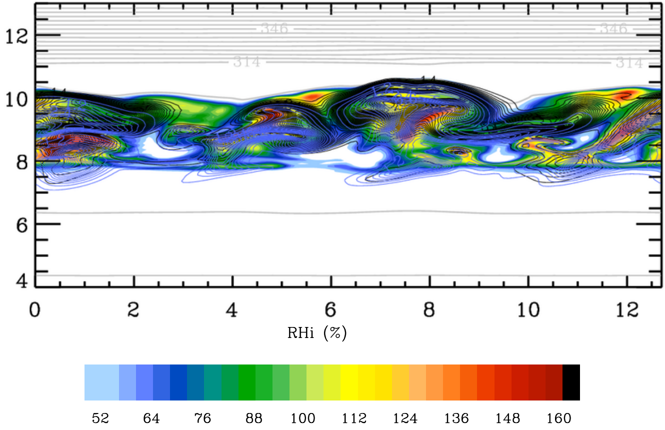
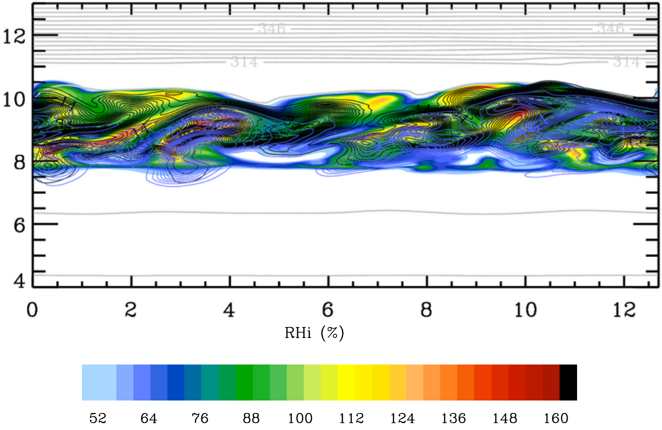
Internal Dynamics in Cirrus

t=100min



Internal Dynamics in Cirrus

t=110min



Internal Dynamics in Cirrus

t=120min