Quasi-biennial oscillation of the tropical stratospheric aerosol layer

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Motivation

Trepte and Hitchman, Nature, Vol 355, 1992

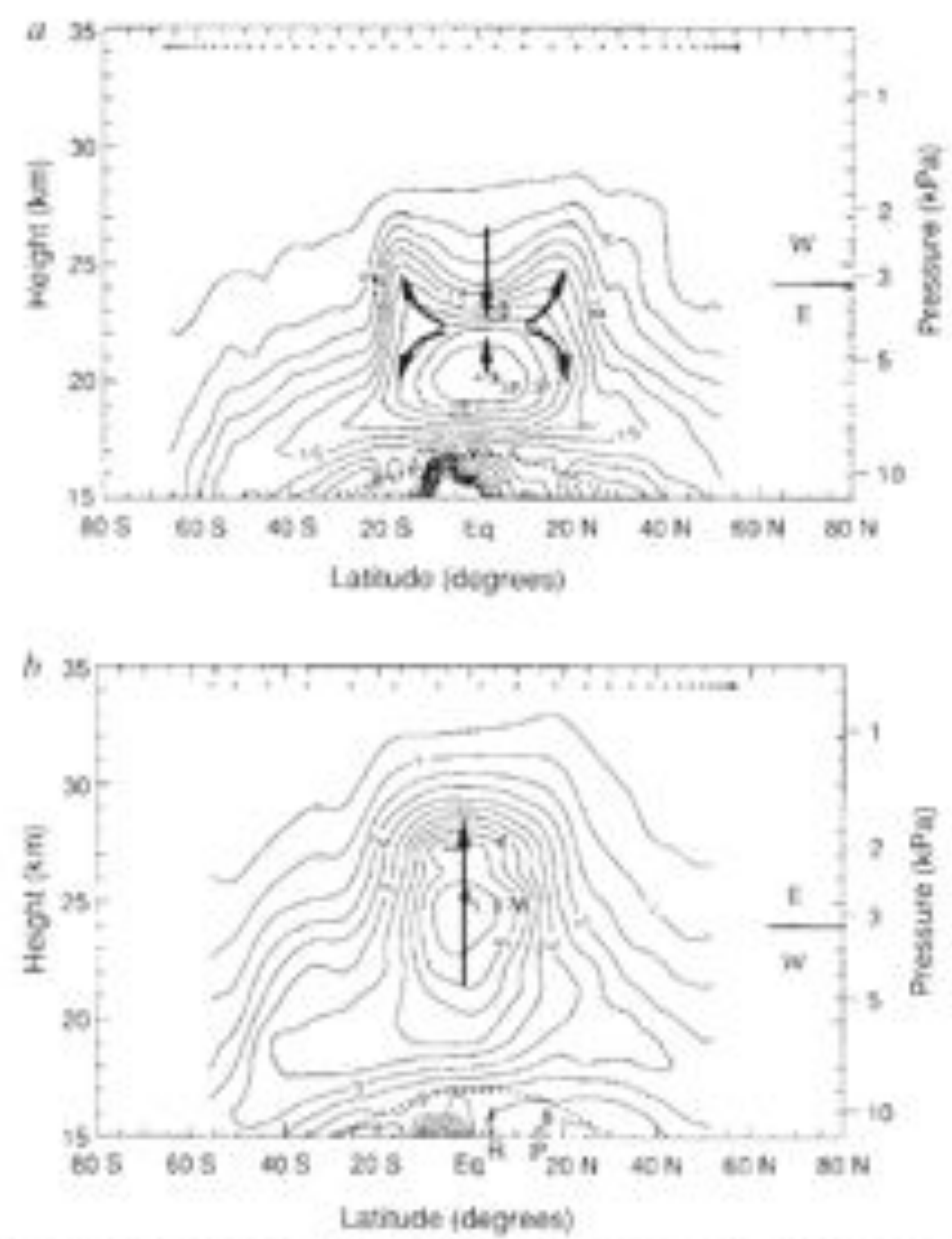

FIG. 3 Latitude-altitude cross-sections of aerosol extinction ratio at 1 μm (refs 13, 14) during two ~40-day periods representative of two different phases of the QBO. *a*, Dominant westerly shear, centred about 11 November 1984, contour interval 2.5; *b*, dominant easterly shear, centred about 4 October 1988, with contour interval 0.5. Crosses indicate locations of the daily average of ~15 profiles. Arrows indicate the inferred QBO circulation based on the aerosol distribution. The altitude of the zero wind over the Equator is transcribed from Fig. 1 at the right of each section. The climatological tropopause is indicated by a dashed line, where cloud tops can contaminate the aerosol data. R and P indicate the latitudes of Mounts Ruiz and Pinatubo, respectively.

QBO effects in LS aerosol first described in TH92

Extinction SAGEII 1979-1981 & 1984-1991

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Not representative for stratospheric background

Not much attention since then

Background aerosol - neglectable role in climate

However

Trends in the volcanically quiescent layer remained unclear

Discrepancy between observations and models during background (ASAP 2006)

Furthermore

Very simple treatment of LS aerosol in climate models

Interactions between microphysics in LS and climate processes not investigated in detail

This Talk

Describes interaction between aerosol processes and the QBO - one of the dominant modes of climate variability

Focus: Tropics,

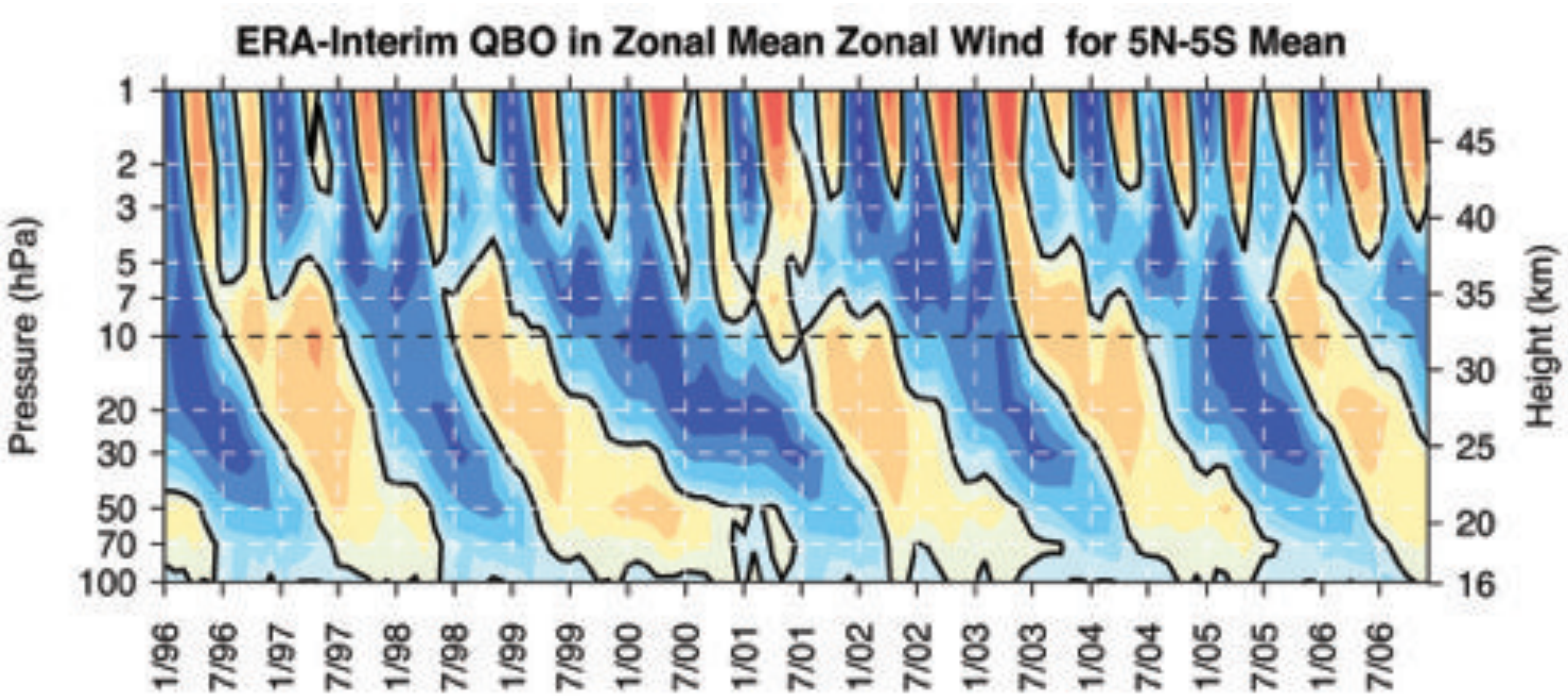
.... by means of a model.

Compare with satellite observations.

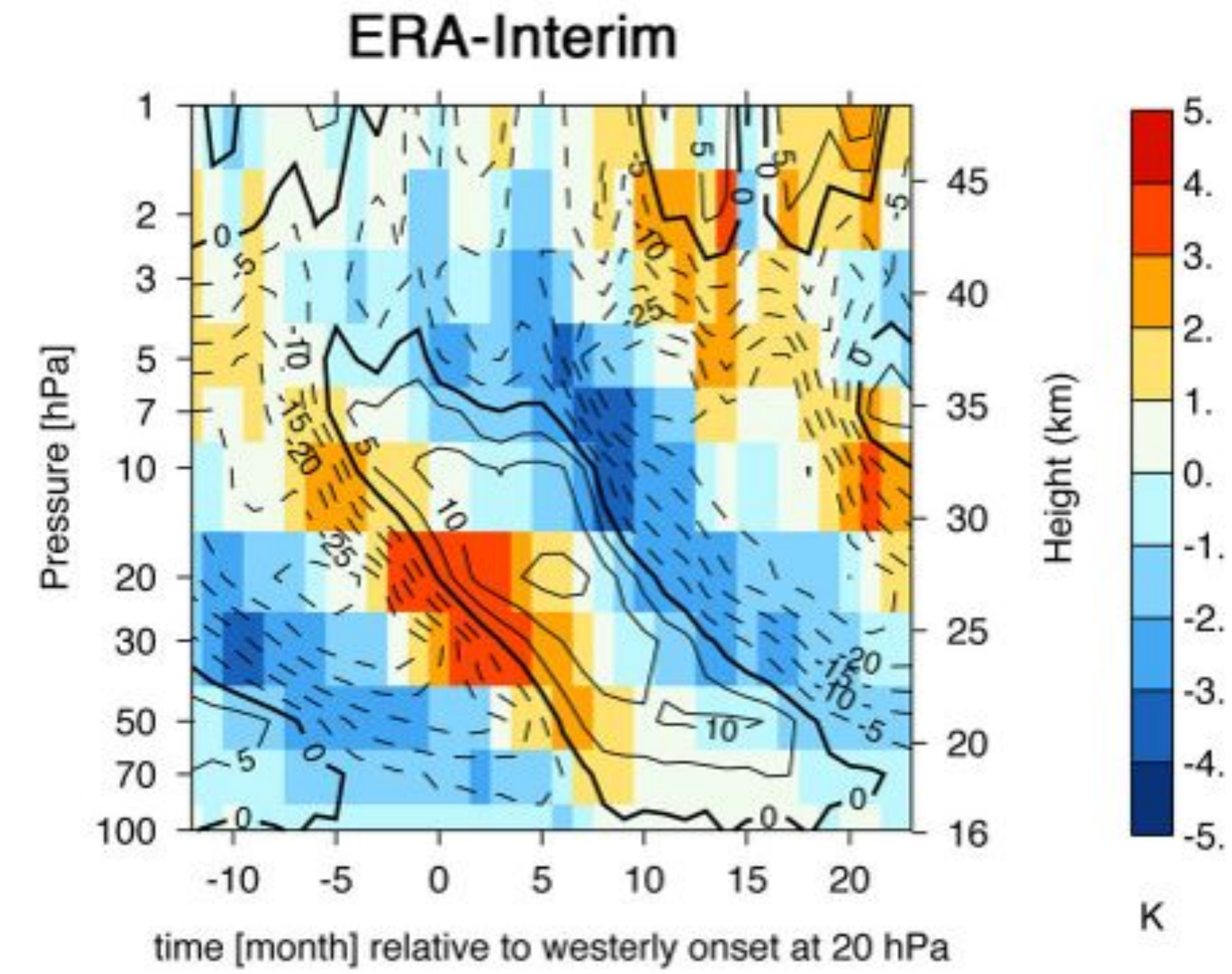
QBO

Tropical phenomenon - reversal of zonal wind - period approx 2y

Affecting climate in many ways

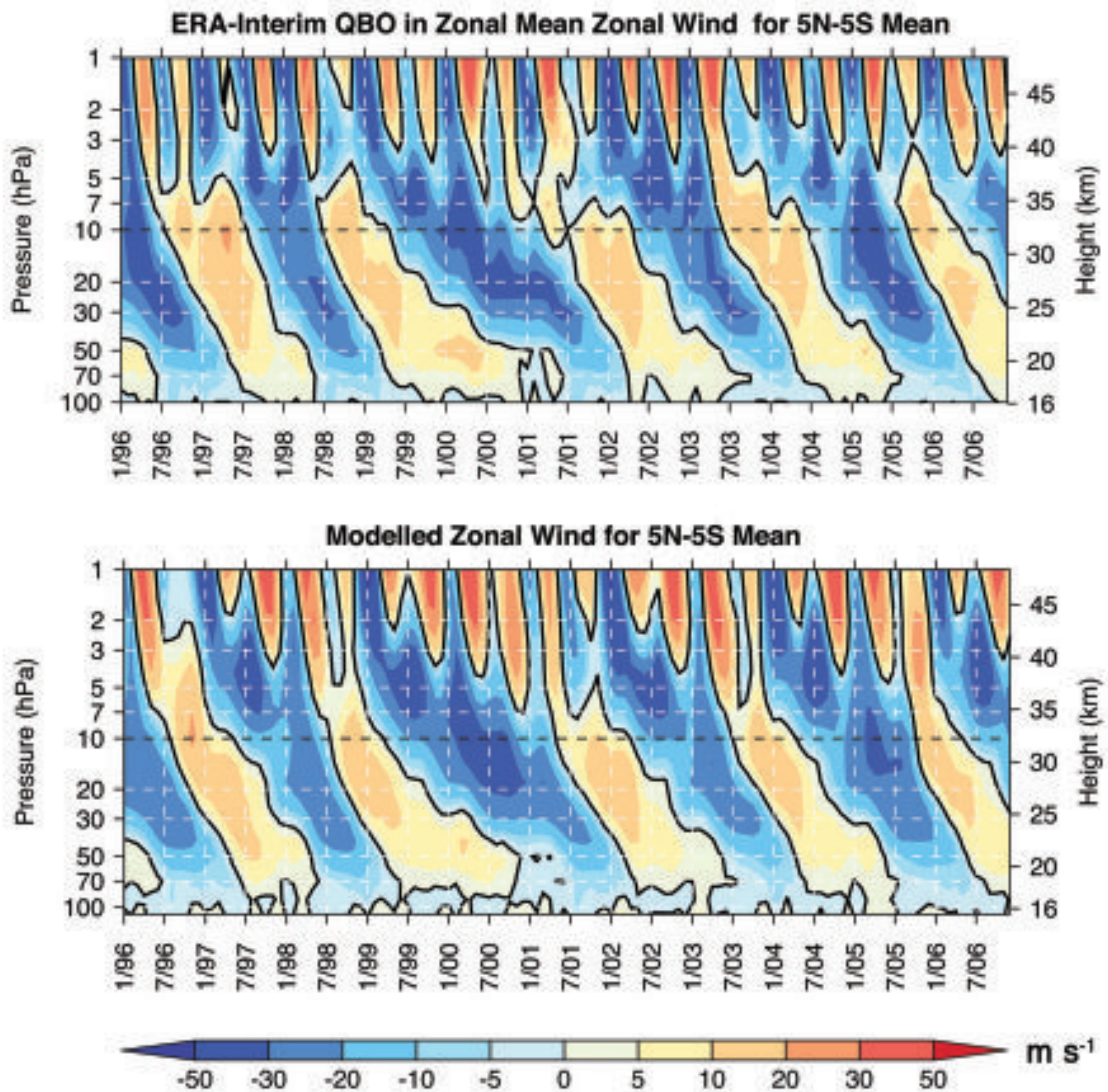


Induces Temperature Anomalies



see Giorgetta et al. J Climate, 2006

Model



Middle-atmosphere GCM (general circulation model) **MAECHAM5** interactively coupled to aerosol size resolving code **SAM2** (Hommel et al., 2011; Timmreck 2001)

Representing well QBO

Nudging of observed winds over Singapore (Giorgetta & Bengtsson 1999; Naujokat, 1986)

2.8x2.8 degree, vertical resolution 1.5 km

Clim. mean SSTs - **no ENSO**

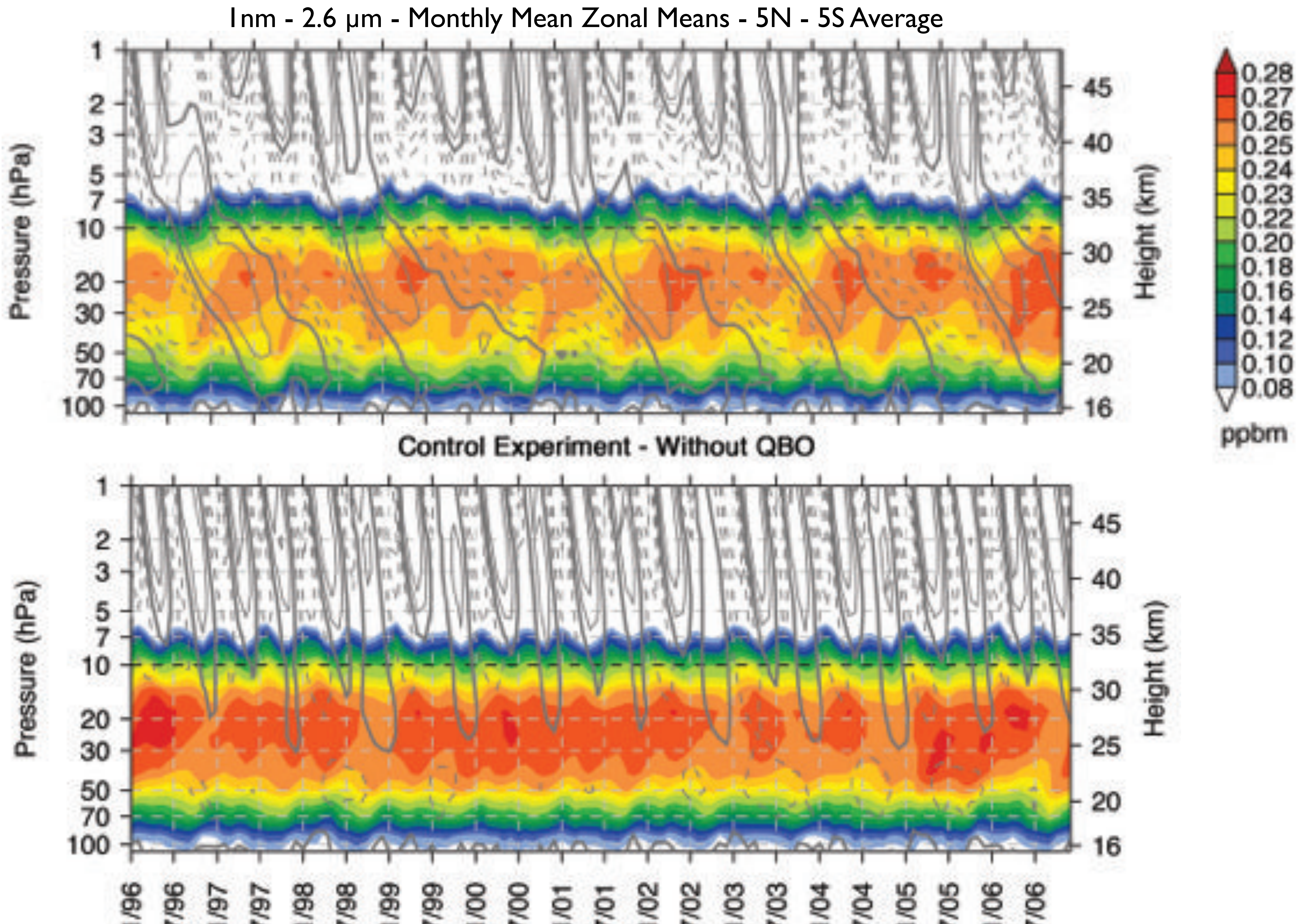
GCM evaluated in several configurations (e.g. Manzini et al., 2006)

Aerosol code SAM2 **resolves** aerosol size in 35 bins between 1 nm - 2.6 µm **(sectional)**

Binary homogeneous nucleation Vehkamäki et al, 2002

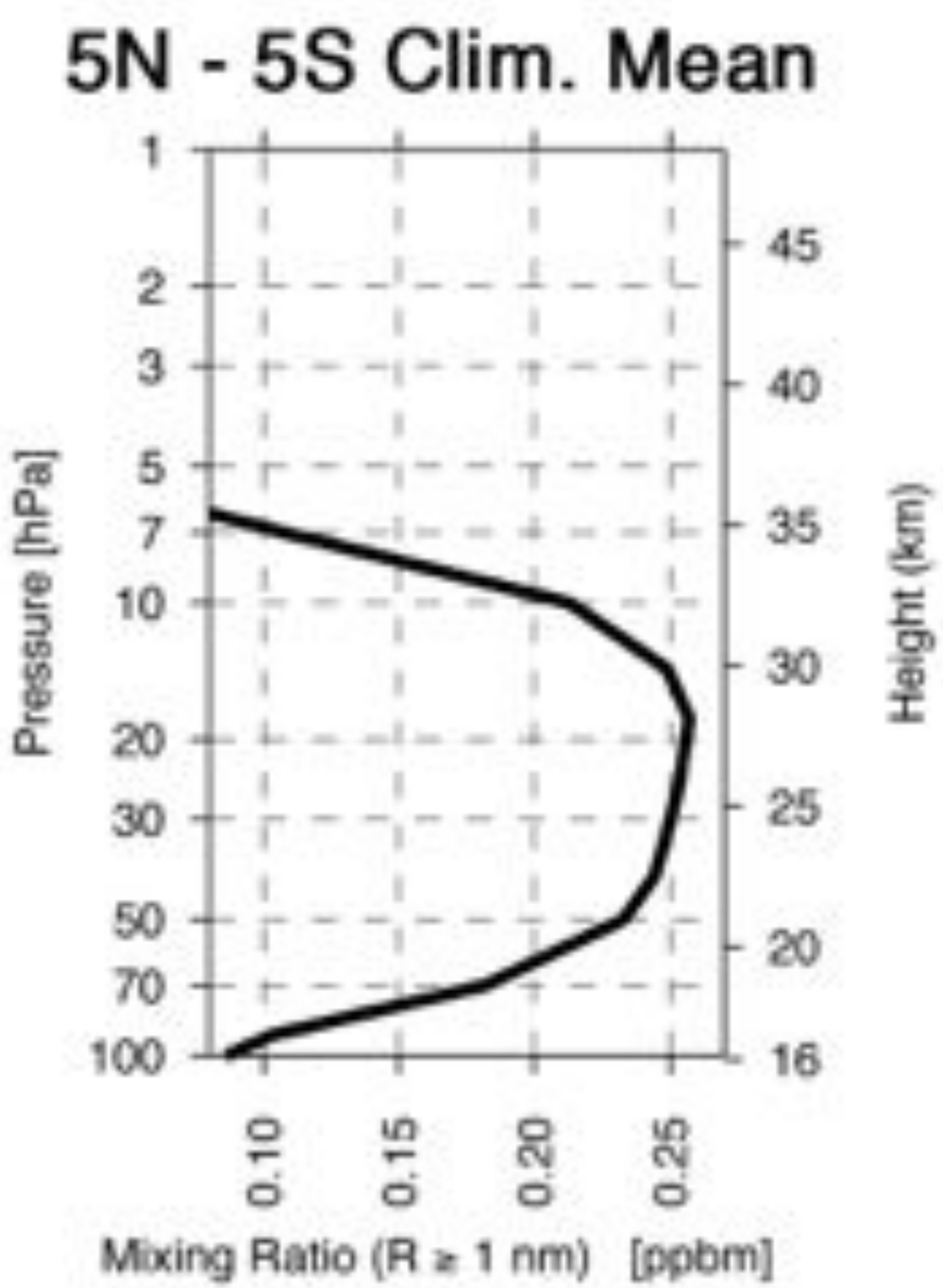
Hommel et al., GMD, 2011; Hommel & Graf, ASL, 2010; Kokkola et al., GMD, 2009

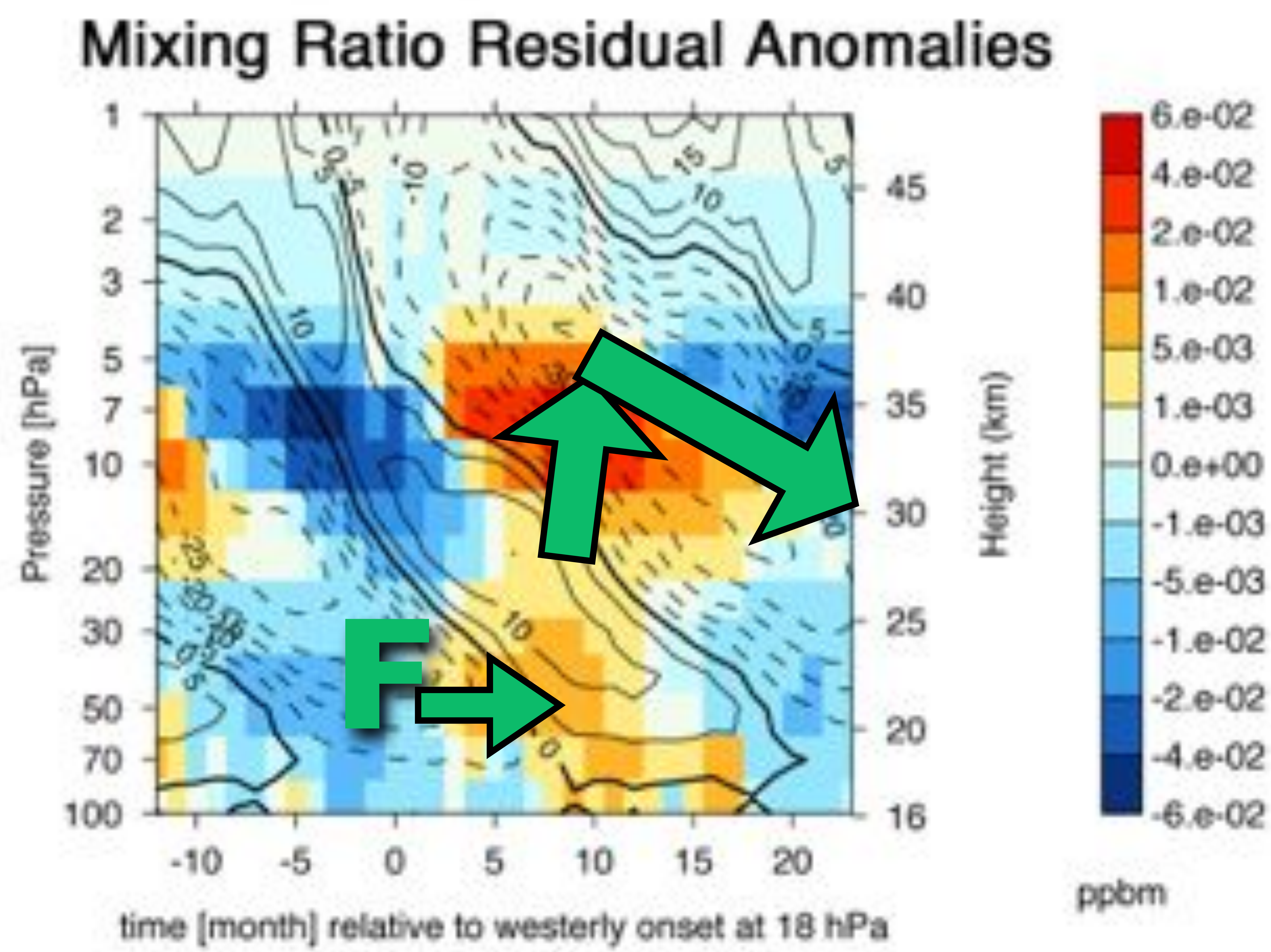
QBO in Aerosol Mixing Ratio



Highly variable nature of Junge layer becomes obvious when compared to a model without QBO

Anomalies - A More Precise Picture





Mainly advection driven - QBO induced negative T anomalies (easterly shear) enhance vertical transport

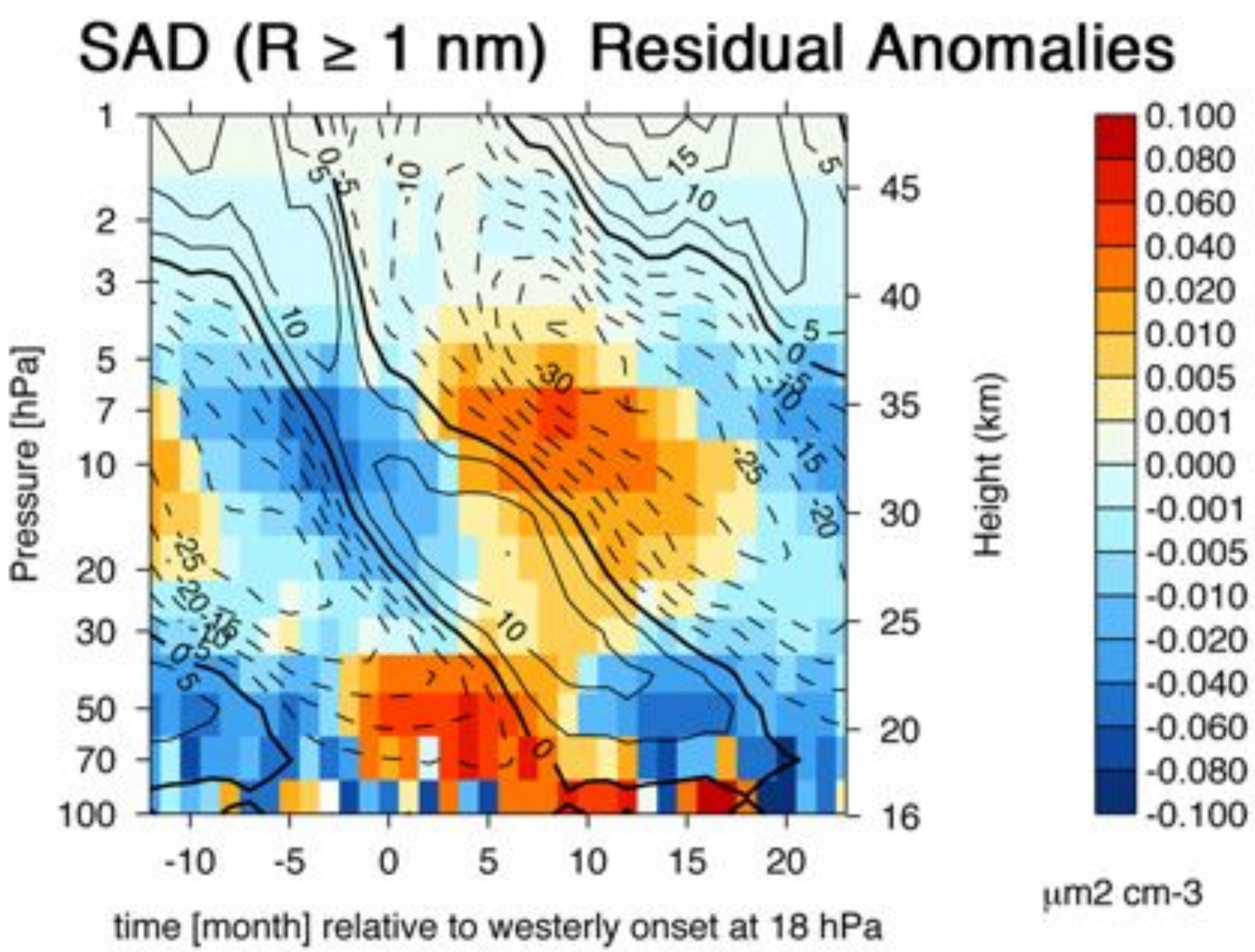
Followed by slow descent of layer during easterly QBO

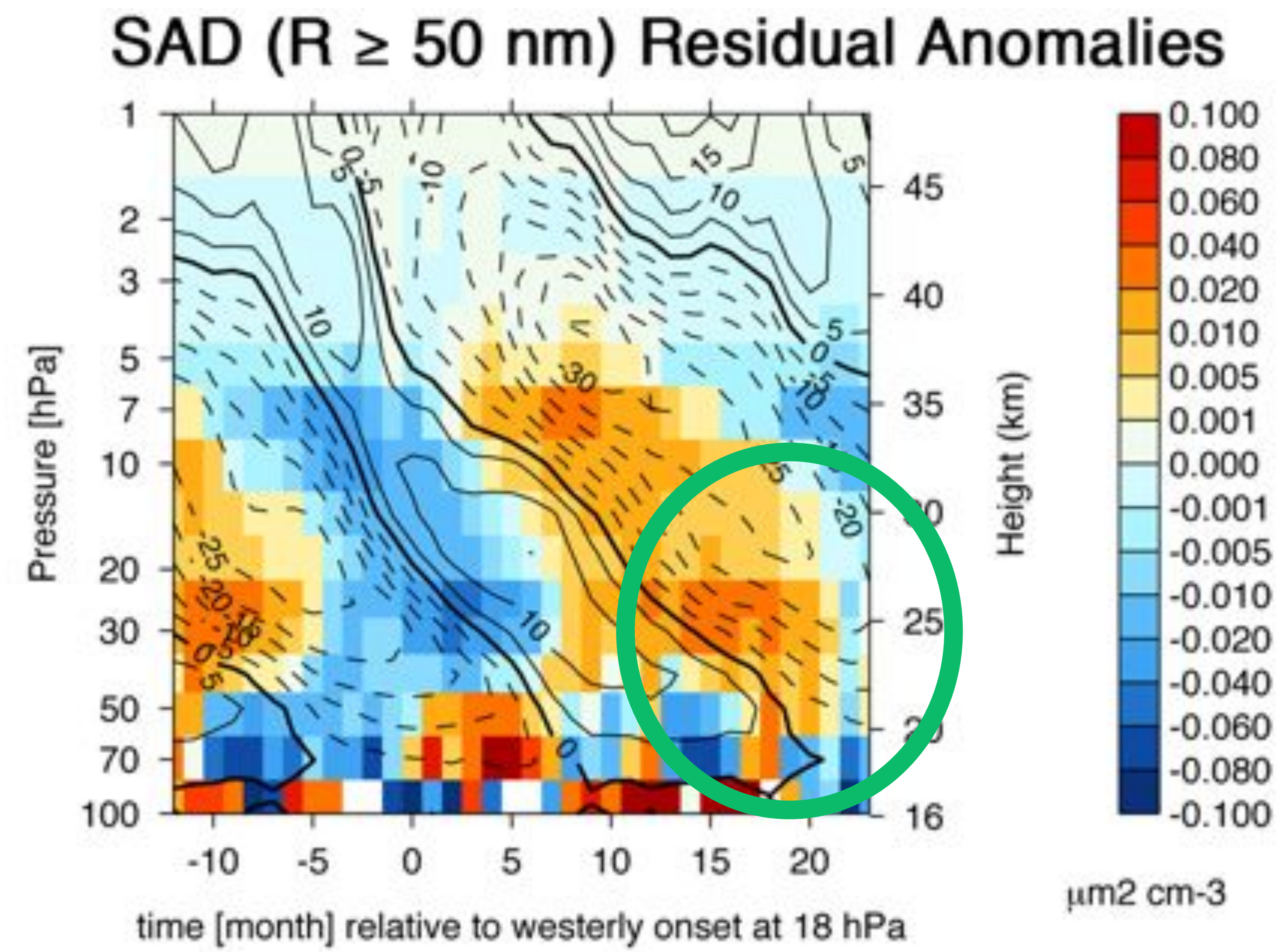
⇒ Layer thickness varies by 5km or more

Similarities to Ozone QBO (e.g. Butchard et al., 2003) - because profiles are characteristically shaped

Integrated Aerosol Size I: Surface Area Density

That is what a satellite would see



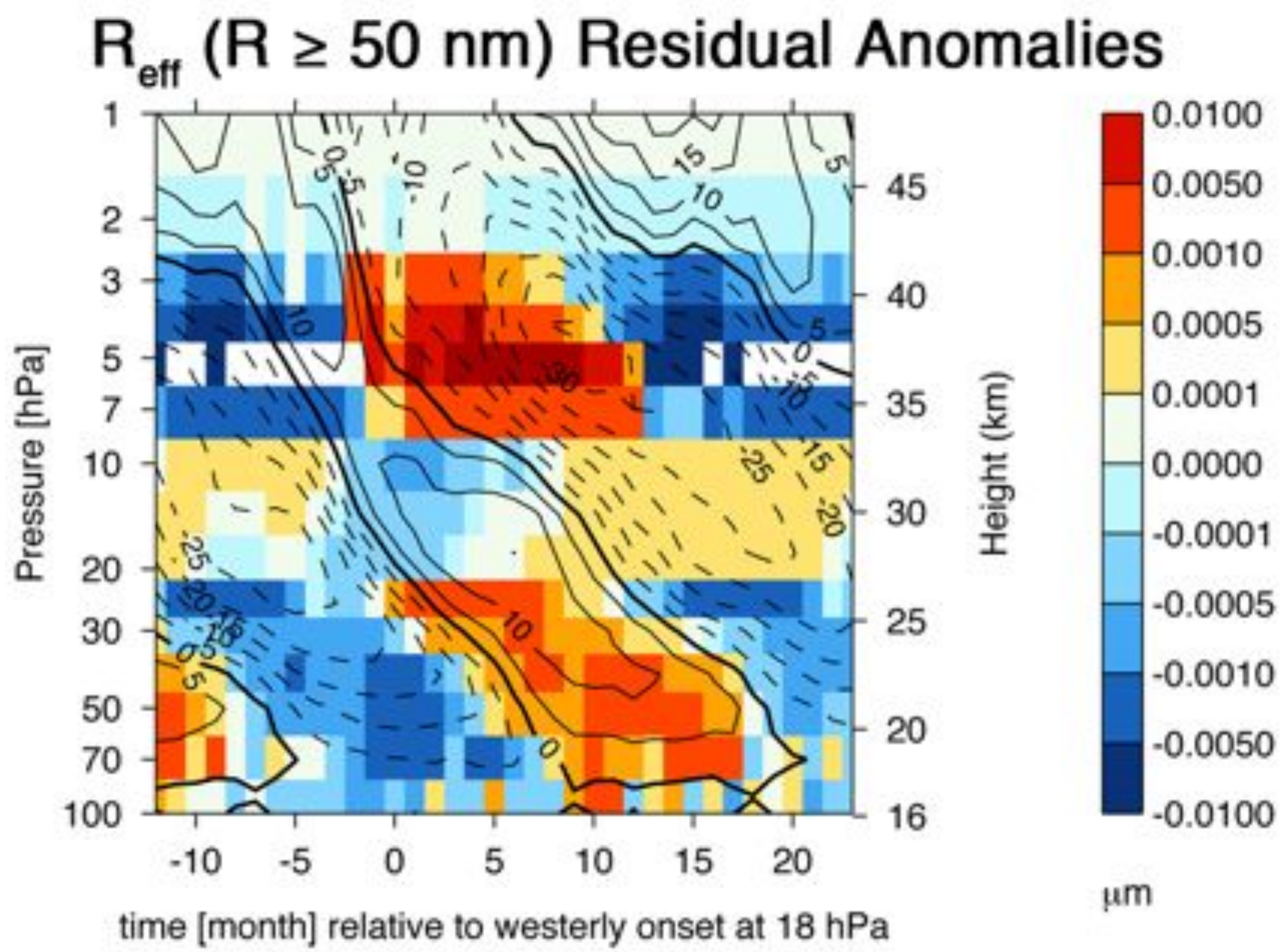


SAD strongly depend on size range considered in integration:

Up to 60 % smaller SADs below 70 hPa if nucleation mode aerosols are not considered (Hommel et al., GMD, 2011)

In central regions QBO anomalies differ: **Non-linearities** between the various aerosol processes imposed by the QBO

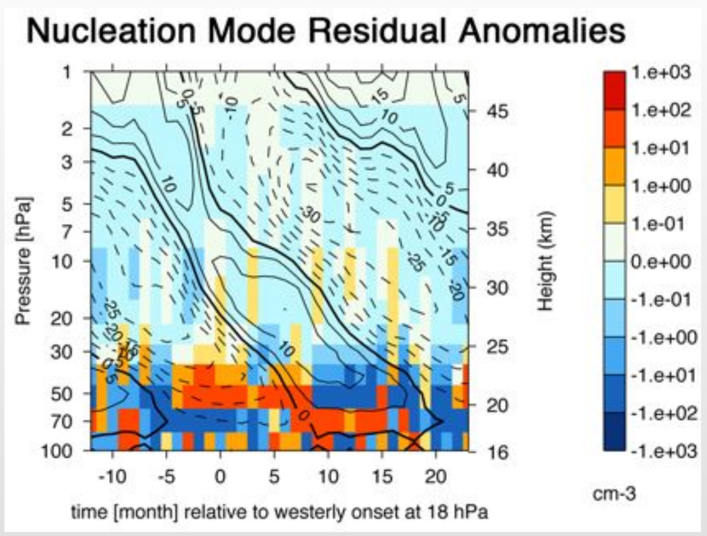
Integrated Aerosol Size II: Effective Radius

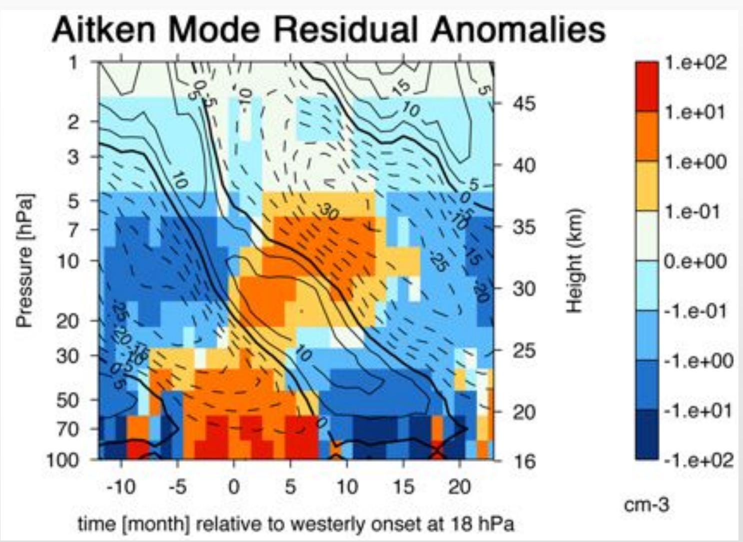


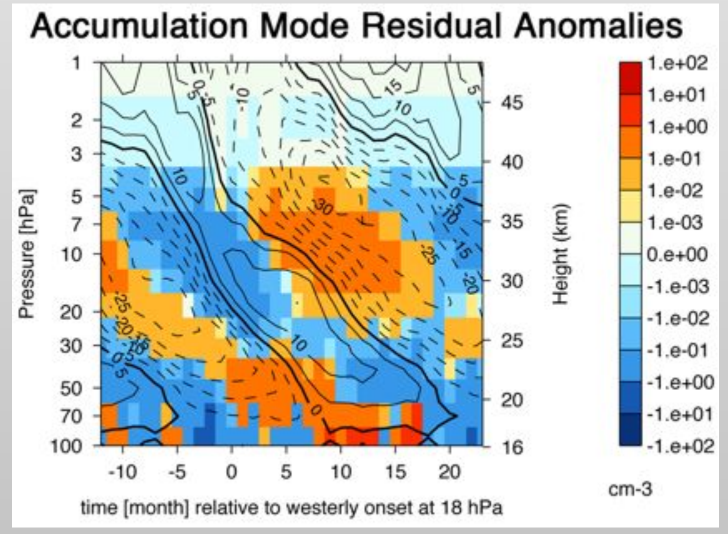
Somehow fuzzy picture ... in evaporation region anomalies in phase with SAD but out of phase below 20 hPa

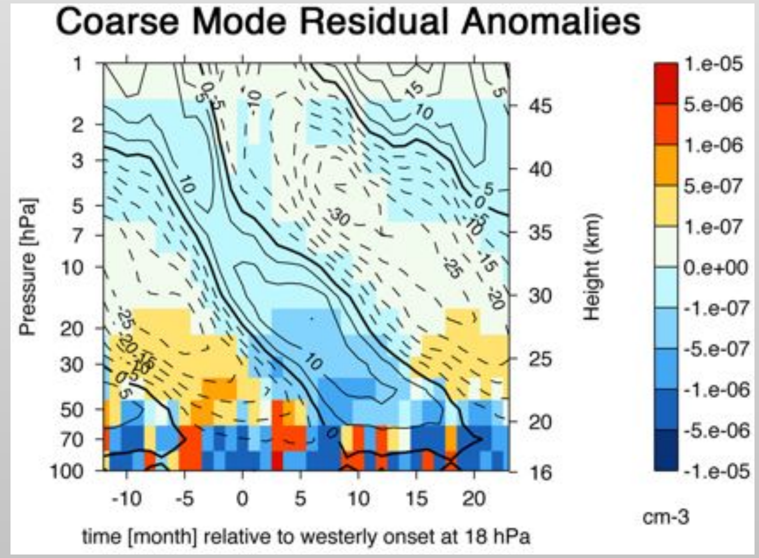
Different QBO mechanisms acting on different aerosol sizes?

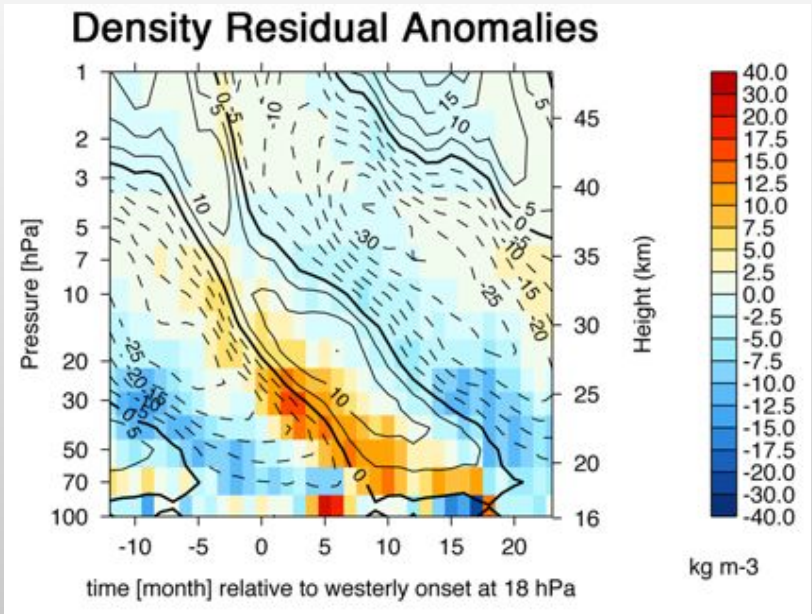
Overview Imposed Modulations by QBO

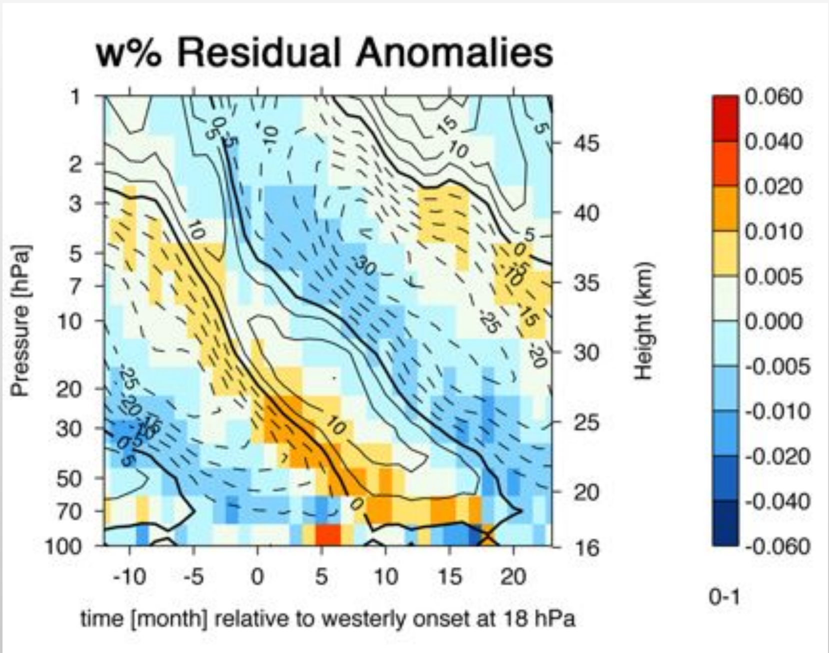












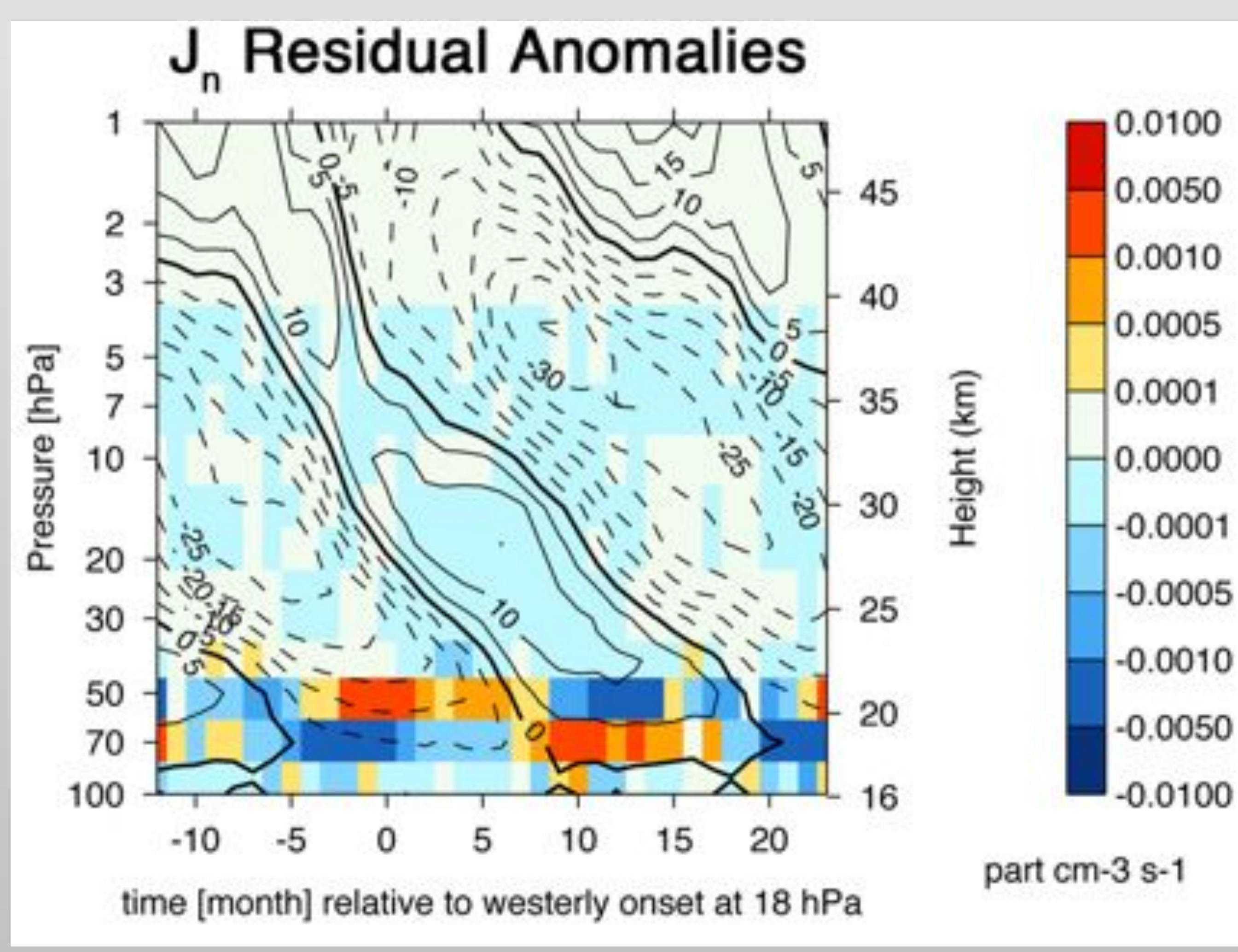
Aerosol Parameter	Percentage Modulation	
	Central Region	Upper Edge
Ozone	*3 - 15 %*	
Mixing Ratio	5-7%	60-90%
SAD	5-7%	>100%
Reff	<5%	20-60%
ND Nucl. Mode	up tp 100%	-
ND Aitken Mode	5-20%	up tp 100%
ND Accu. Mode	<5%	up tp 100%
ND Coarse Mode	<5%	up tp 100%
Aerosol Density	<2%	<1%
H2SO4 w%	5 %	<1.5%

Imposed Modulations on Microphysics

Nucleation can be triggered up to 50 hPa by up to 30 % (Vehkamäki BHN parametrisation)

Due to 1-3 K cooling by QBO

Nuclei then readily uplifted to 30 hPa and above

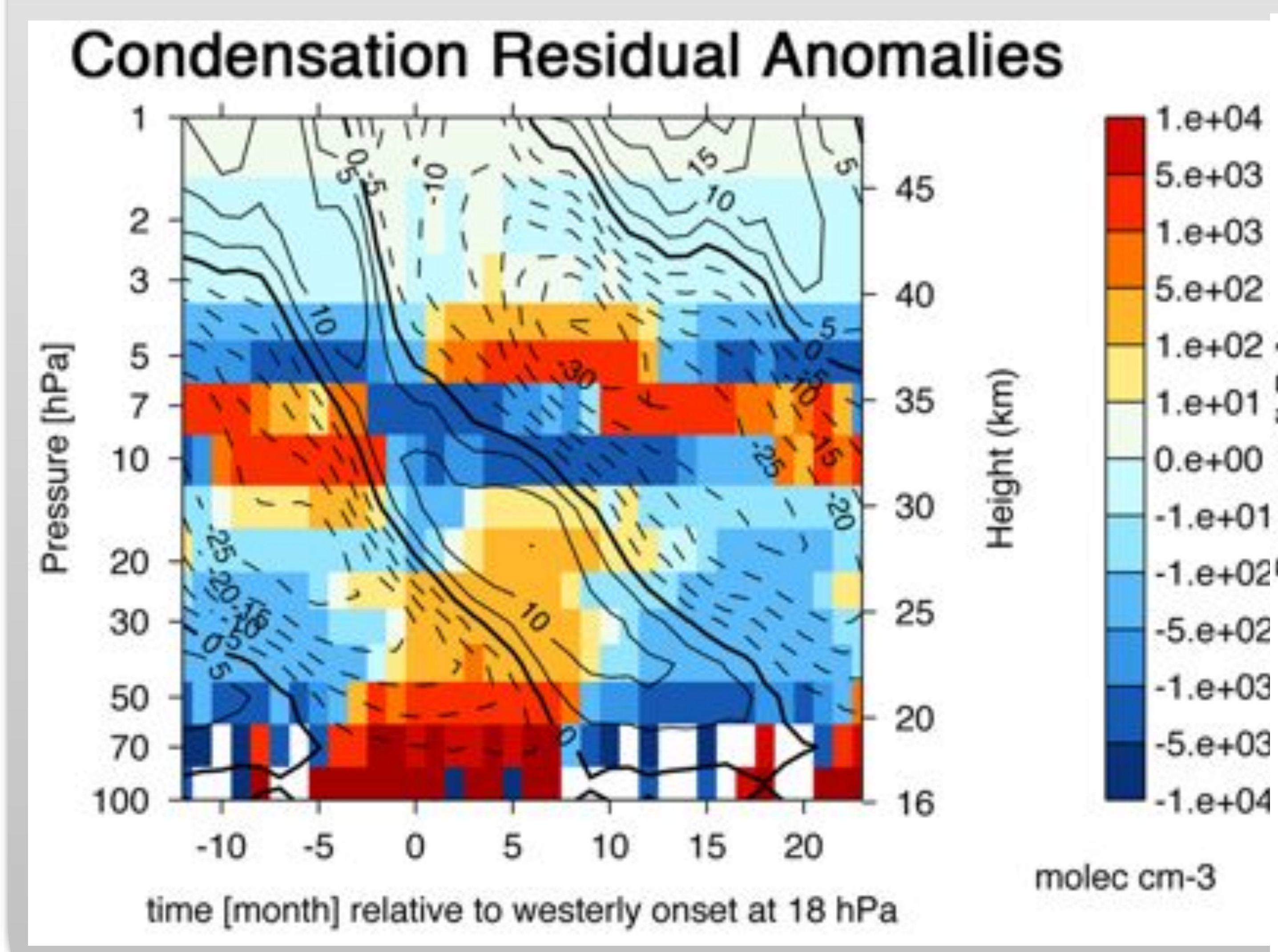


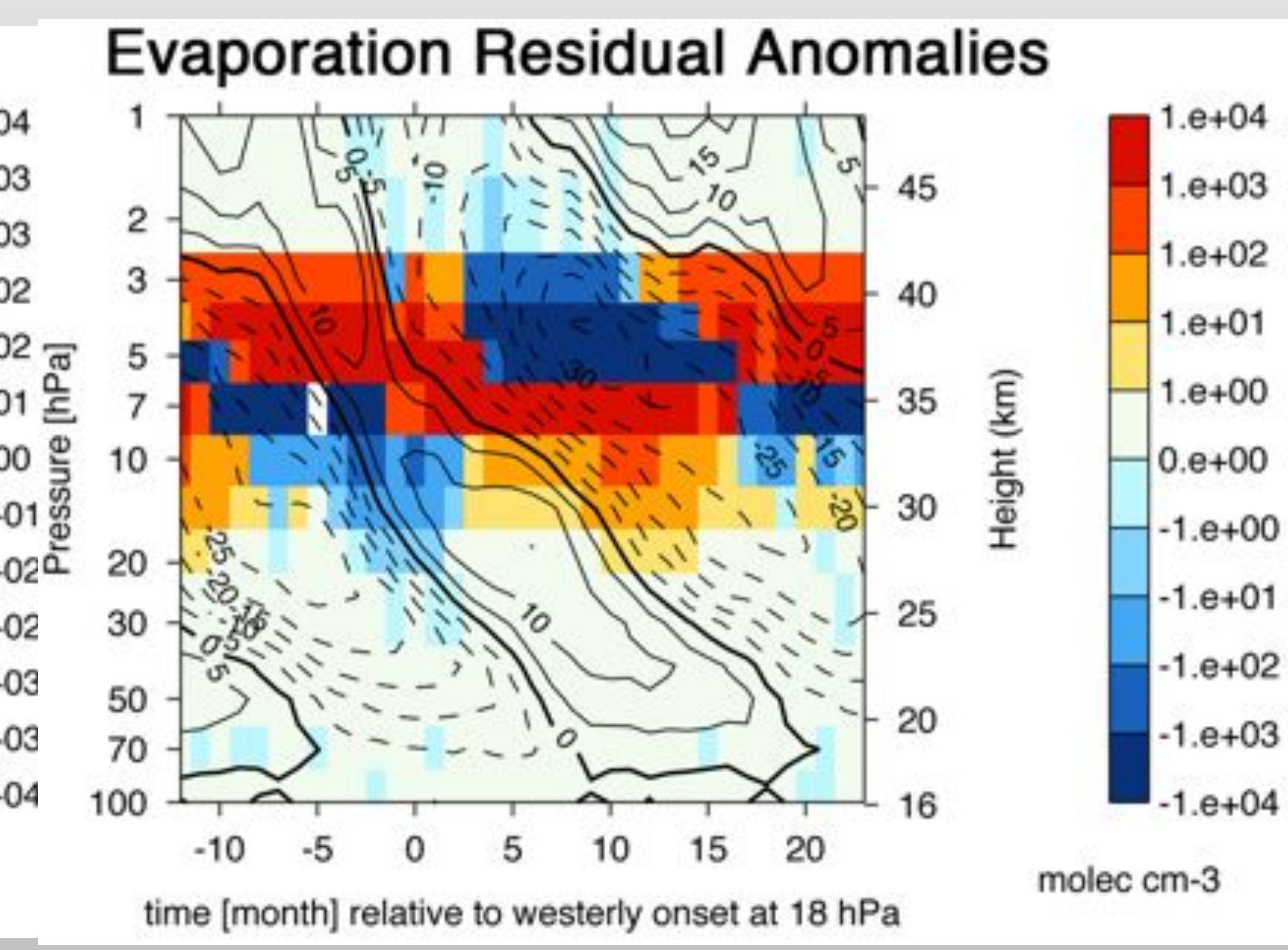
H2SO4 mass transfer is a reversible process

Correlate well with intermediate sitze aerosols

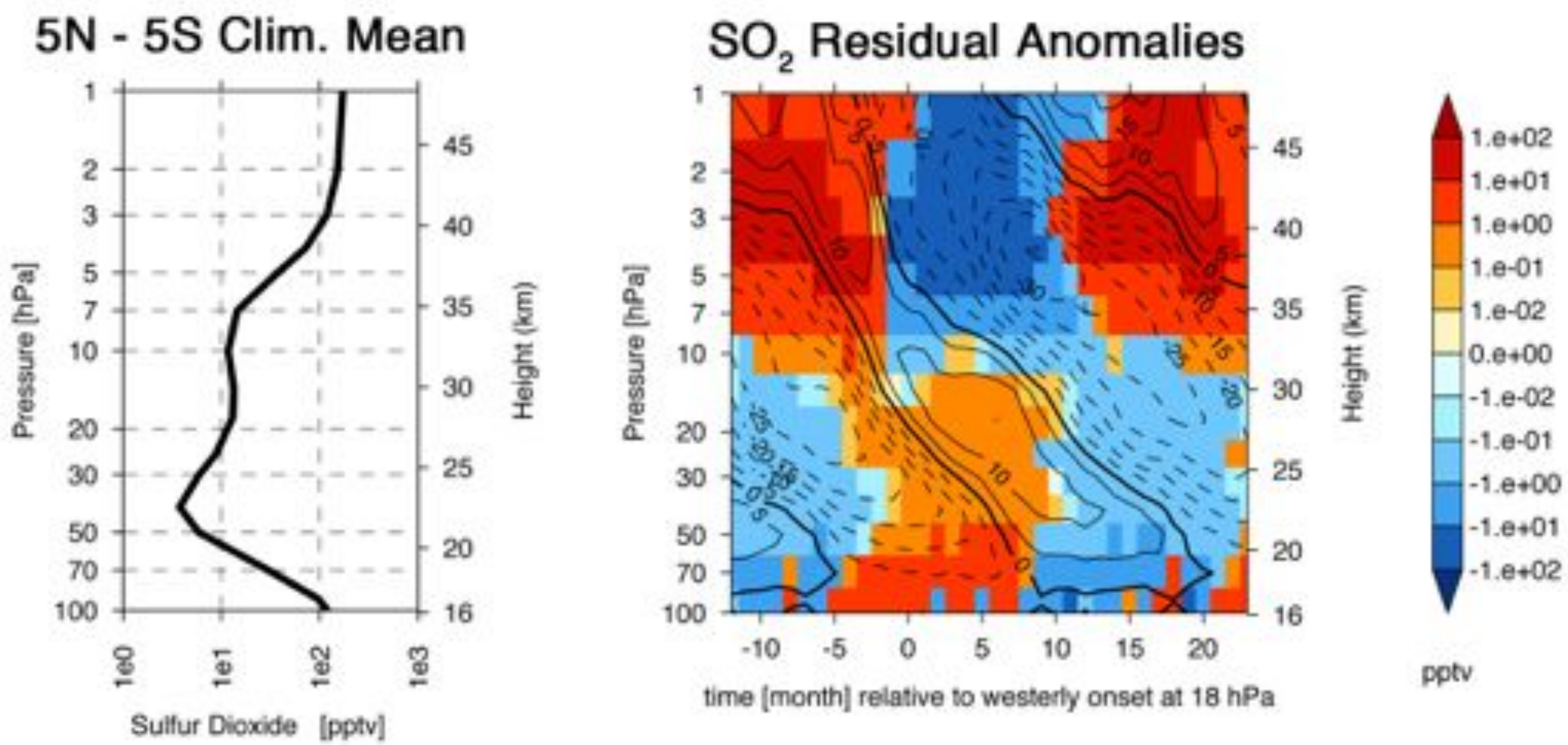
Modulated by 10-60%

Condensation / evaporation expressed as time-mean concentration that is transferred between gas and liquid phase



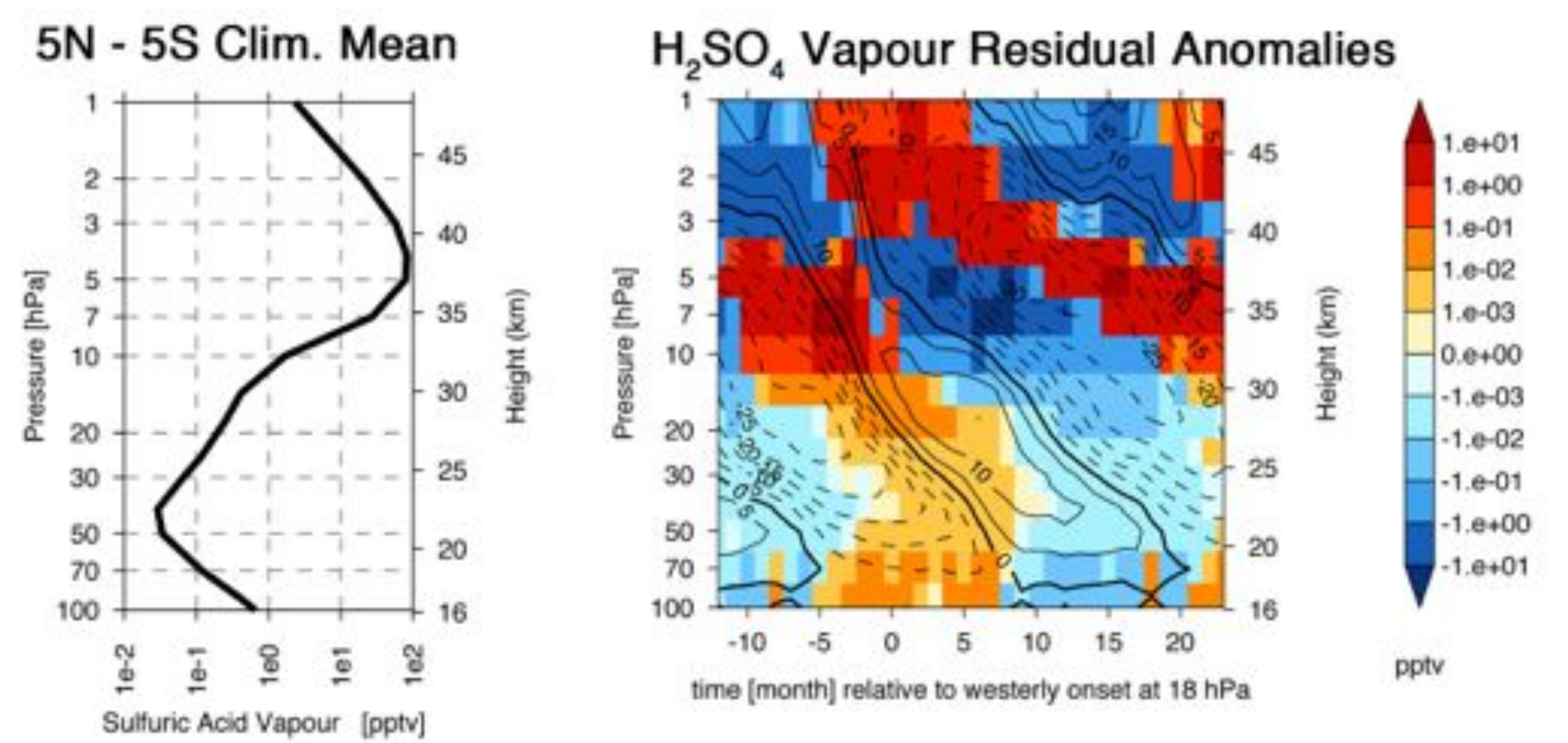


Imposed Modulations on Precursors



Distinct modulations by QBO

⇒ contribute to variability of tropical LS aerosol load



H2SO4 vapour: Although very short lived, anomalies found are a **fingerprint** of SO2 modulations

DMS does not play a role - even in extratropical STE (Hommel et al., GMD, 2011)

Comparison to observations

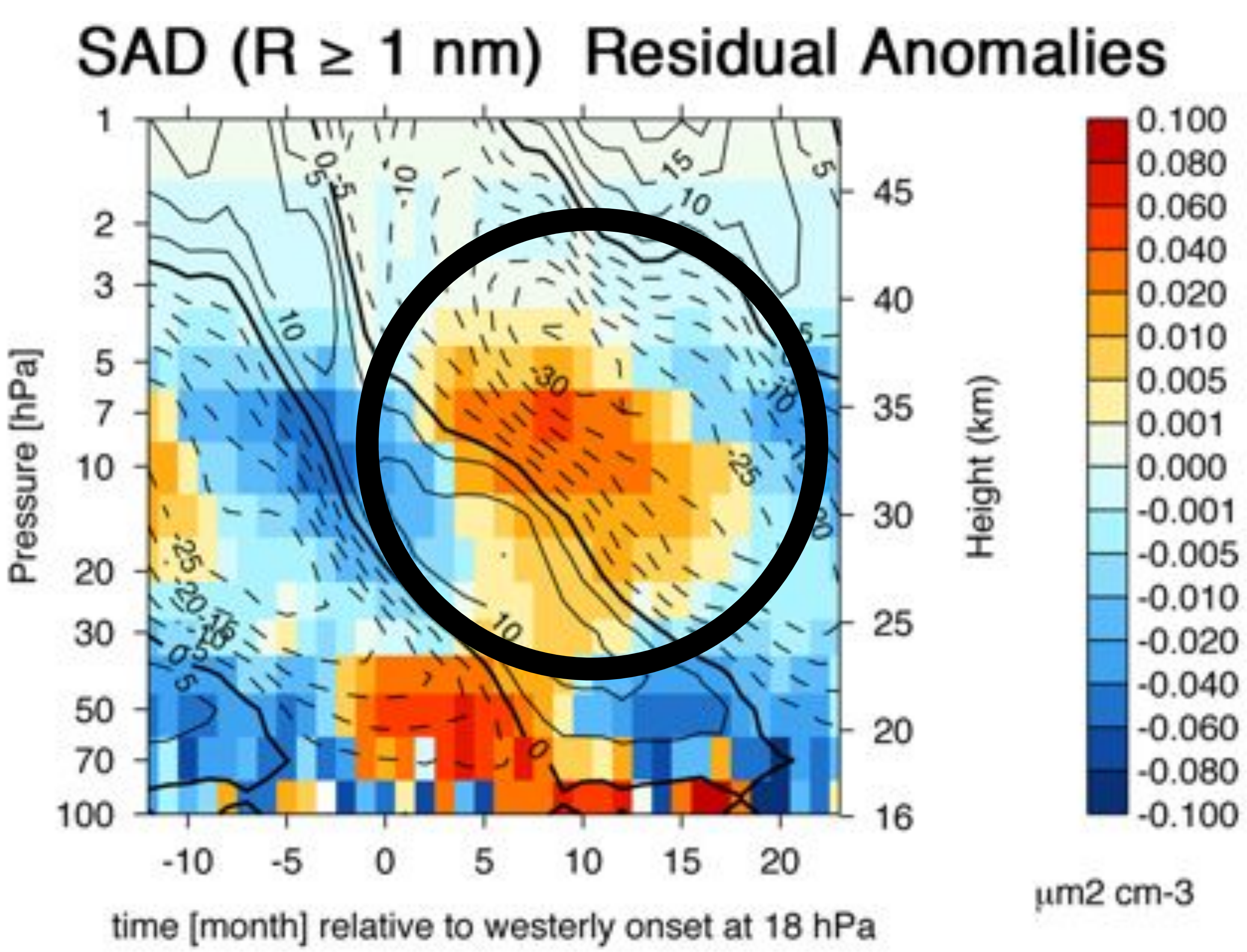
Not much to compare ...

SAGEII based SADs from

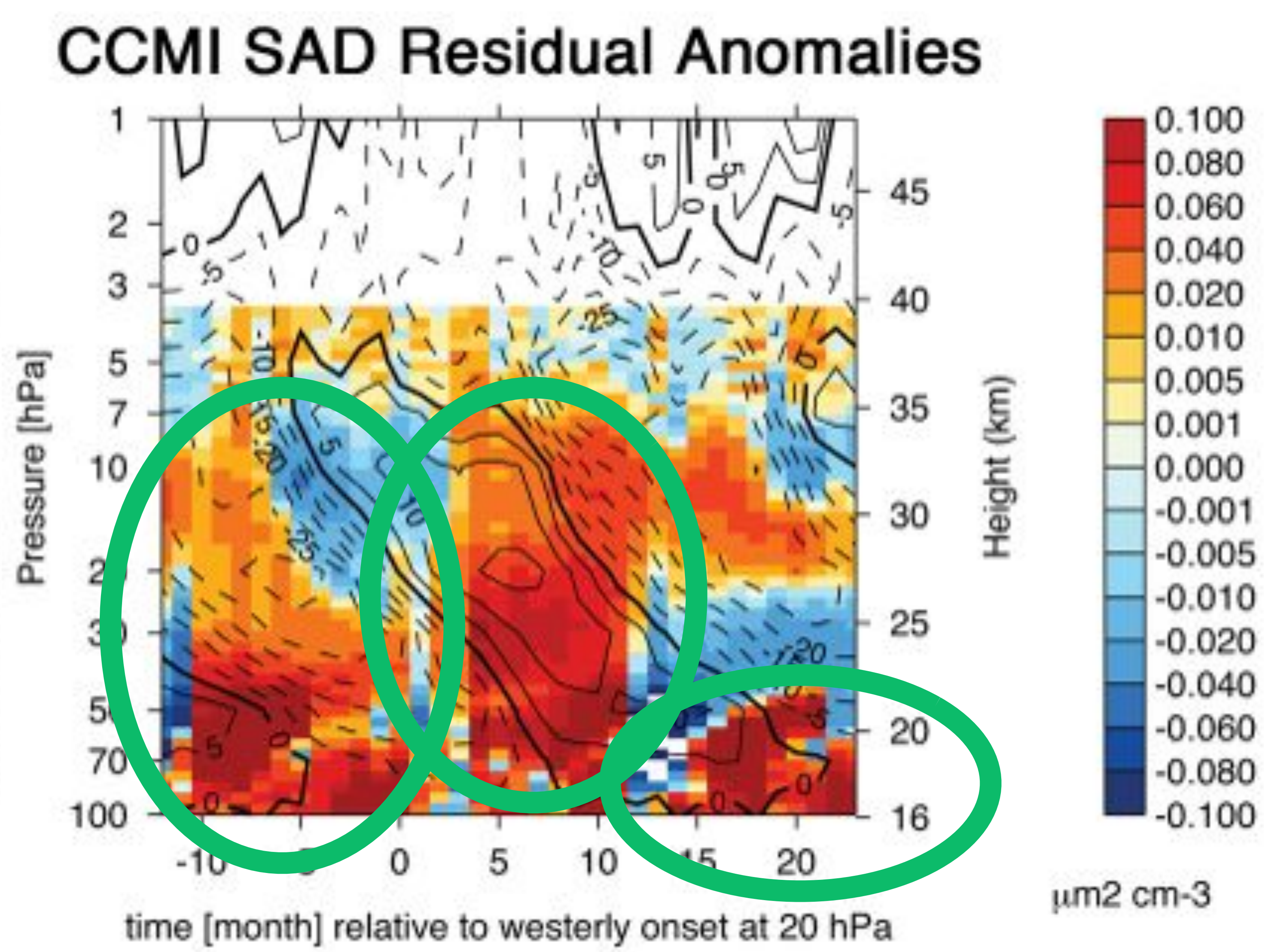
- SPARC ASAP 2006
- SPARC CCMVal & CCMI
- Wurl et al., ACP, 2010 (University of Oxford, optimal estimation, SAD, VD, Reff)
- Baumann et al., JGR, 2003a,b (NASA AMES, Reff optimised, SAD, VD)
- *HALOE?*

Following slide: ASAP, CCMVal, CCMI (Others too short, end in 2001 and 1999)

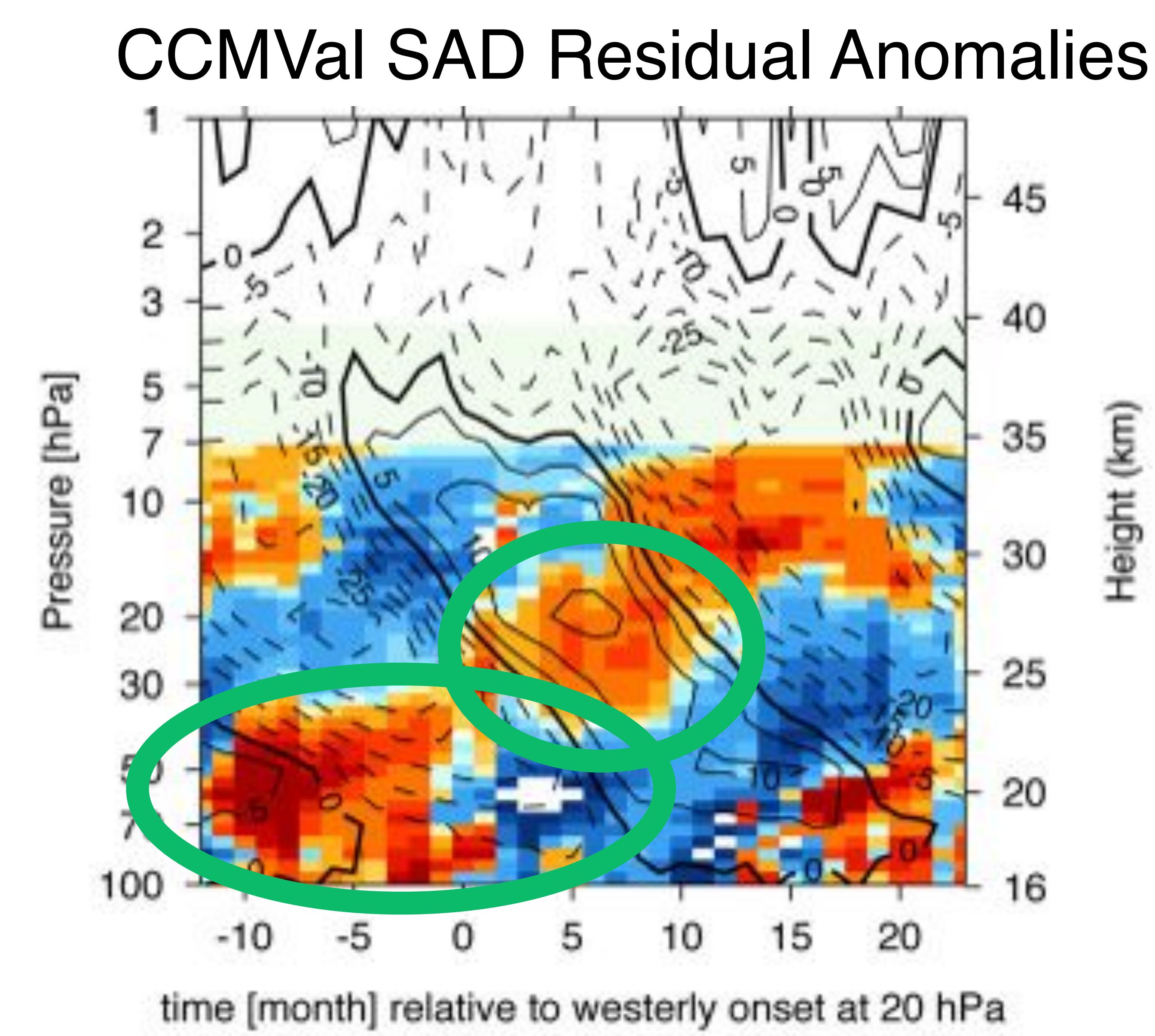
Surface Area Density



Model



SAGEII vn7 +CALIPSO

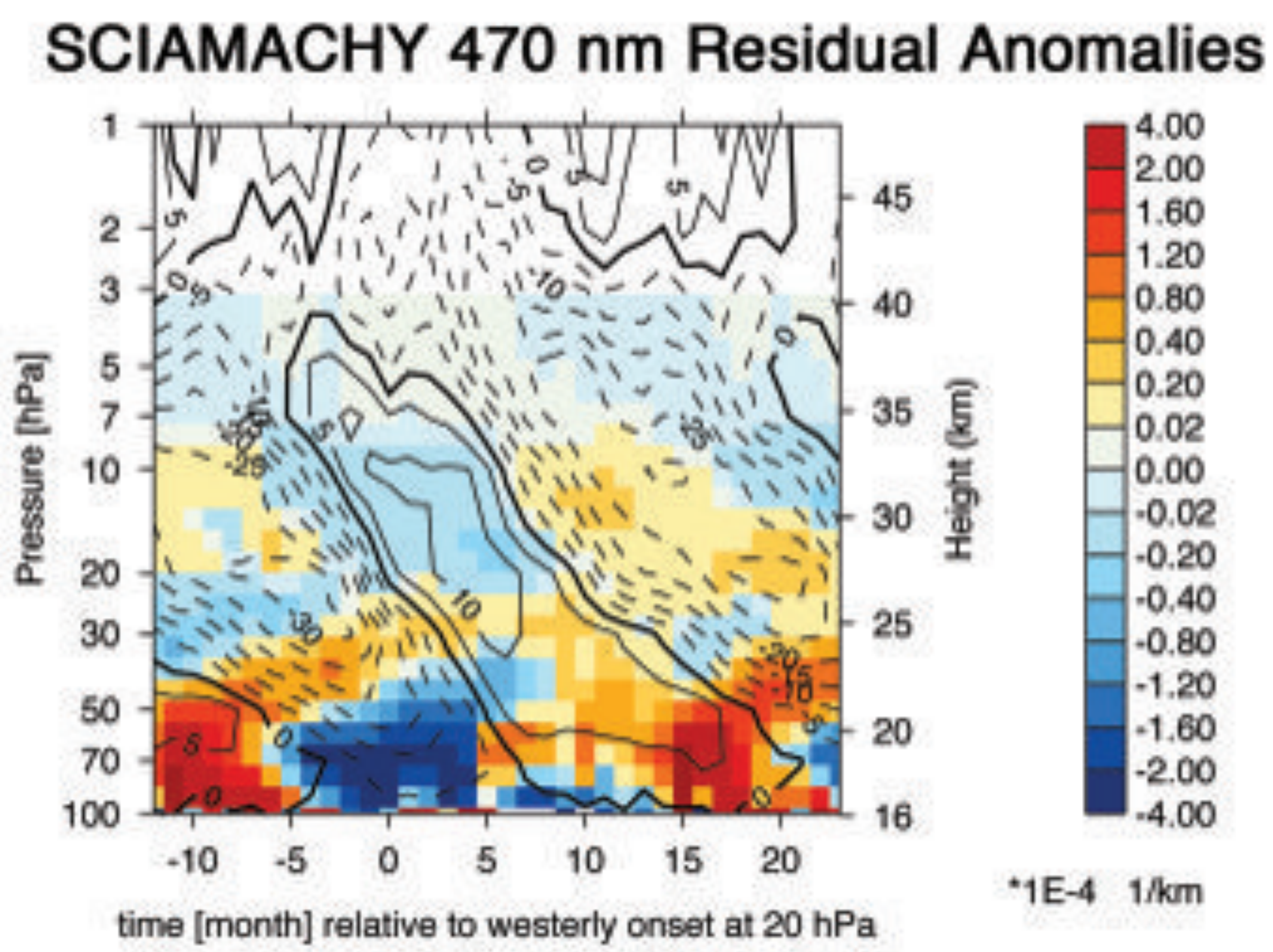


SAGEII vn6.2 + averaging

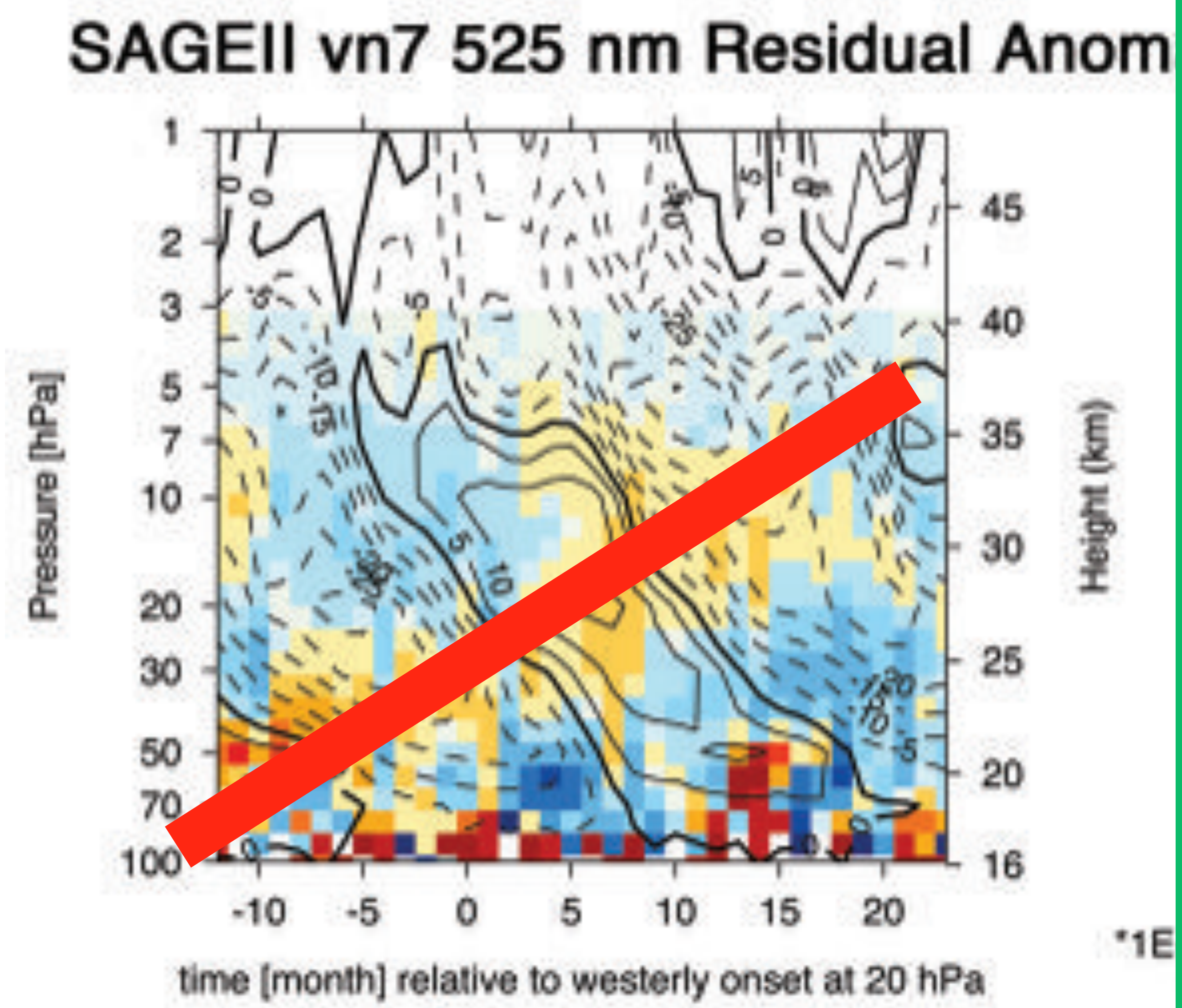
More **differences** than **similarities** - reason?

Satellite based climatologies from different sources (SAGEII+CALIPSO) and gap filling?

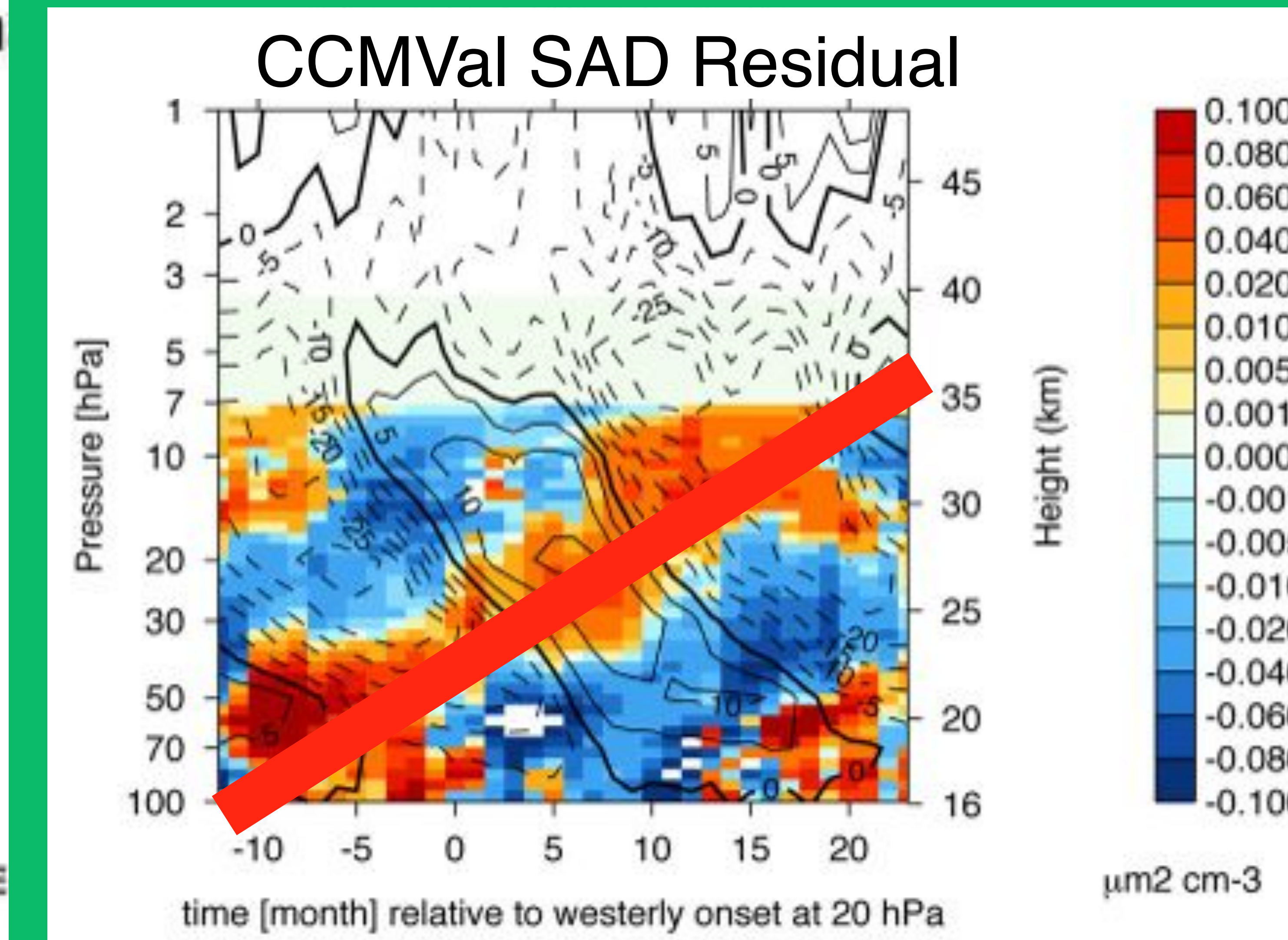
Extinction



Aug 2002 - Apr 2012



Jan 1996 - May 2005



Obvious similarities to SAGEII extinction anomalies

Agree to large extent

SCIAMACHY volcanically influenced? (Lena A Brinkhoff's talk Monday on SCIAMACHY aerosol record)

Not much difference between SAGEII vn7 & vn6.2 ⇒ but huge difference in SAD anomalies?

Size intended to be derived from SCIAMACHY in near future

Summary

The tropical Junge layer is anything but static

Strength of QBO effects depend on aerosol size - may be only partly inferable from remote sensing

+ Non-linear interactions between several process

+ Interfere with effects imposed by annual cycle at TTL

⇒ Irregular anomaly pattern above below 70 hPa

There is also a large influence of the Asian monsoon system on tropical LS aerosol in the model!

Some gaps between model and observations remain

Implications for climate processes have to be investigated ⇒ ROMIC

... new German middle atmosphere research initiative (BMBF)