# Quick Summary of Aqua Planet Experiment (APE)

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WTK Workshop at CPS 14 March 2013

We have come back to the Earth,
the planet we know best.

But understanding the behavior of the atmosphere (or its models) is still not an easy task even in the simplest set-ups.

# Background

# The Gap between Simulation and Understanding in Climate Modeling

BY ISAAC M. HELD

Should we strive to construct climate models of lasting value? Or should we accept as inevitable the obsolescence of our models as computer power increases?

**THE NEED FOR MODEL HIERARCHIES.** The complexity of the climate system presents a challenge to climate theory, and to the manner in which theory and observations interact, eliciting a range of responses. On the one hand, we try to *simulate* by capturing as much of the dynamics as

the stated goal of improving these comprehensive models.

Due to the great practical value of simulations, and the opportunities provided by the continuing increases in computational power, the importance of understanding is occasionally questioned. What does

Held (2005) Bulletin of the American Meteorological Soc.

[ English | Japanese ] [ GFD Dennou Club / dcmodel ]

# GFD Dennou Club Dcmodel project

## What is dcmodel?

The goal of dcmodel project is developing hierarchical numerical models for fluid dynamics in Earth and planetary sciences.

## Products

### Fluid models

**agcm5**
A general circulation model based on primitive equation system (Fortran 77, old project)

**DCPAM**
A general circulation model based on primitive equation system (Fortran 90, new project) for planetary atmospheres with spmodel as a dynamical core

**deepconv**
A two-dimensional non-hydrostatic fluid model

**dynamo**
A MHD dynamo model in a rotating sphere and spherical shells (written with spmodel library)

**spmodel**
Hierarchical spectral models for geophysical fluid dynamics (equation-like expression of ISPACK covered with Fortran 90 interface)

**ISPACK**
Spectral transformation library for numerical fluid dynamics and barotoropic / shallow water models with plane or spherical geometries

**gms**
A grid model development tool and sample programs

**IGModel**
An icosahedral grid atmospheric model

### Energy model

**oboro**
An equiribrium cloud condensation model by using Gibbs free energy minimization method

**dcrtm** (Sorry, this page is described in Japanese)
A radiative transfer model for planetary atmospheres

### I/O library

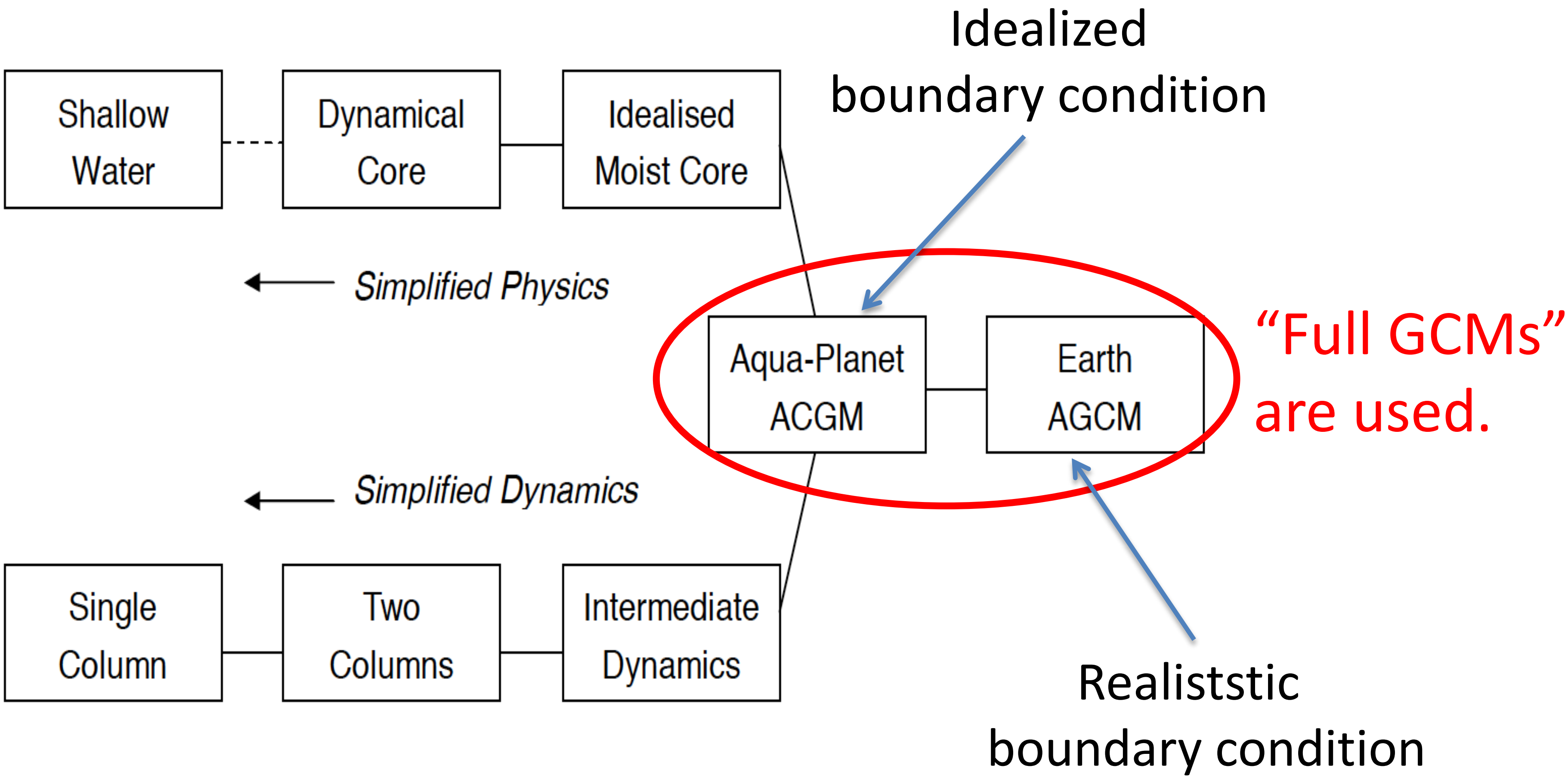
**gtool5**
Fortran 90/95 library for hierarchical numerical models

We have been developing
a hierarchy of numerical models.

地球流体電脳倶楽部
GFD Electric brain Club

Still a long way to go…
(Very limited human resources.)

# Aqua Planet Experiment in the hierarchy of models




Blackburn and Hoskins (2013)

# The Earliest Aqua Planet Experiment

## Hayashi and Sumi (1986)

August 1986 Y.-Y. Hayashi and A. Sumi 455

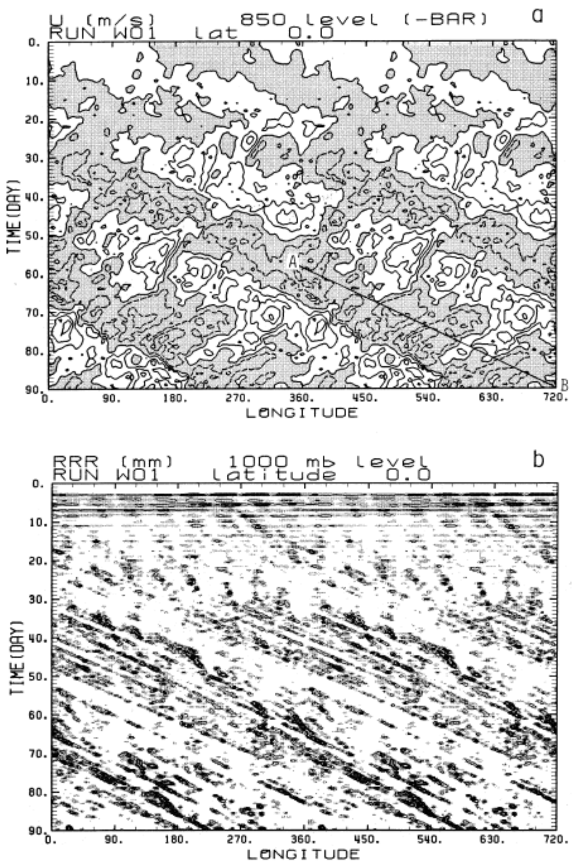



Fig. 3 Longitude-time sections of (a) 850 mb zonal wind deviation ($u'$) and (b) precipitation per 12 hours. The figures are duplicated in the longitudinal direction to clarify the periodicity. The contour intervals are 2.5 m/s for $u'$ and 2.5 mm/12 h for precipitation. The regions of (a) easterly ($u' < 0$) and (b) precipitation greater than 1 mm/12 h are shaded. The line segment AB denotes the phase line ($c_0$ = 15 m/s) along which the composite structures are constructed.

U

Rain

features in the numerical model

observed features

OLR (cloud activity)

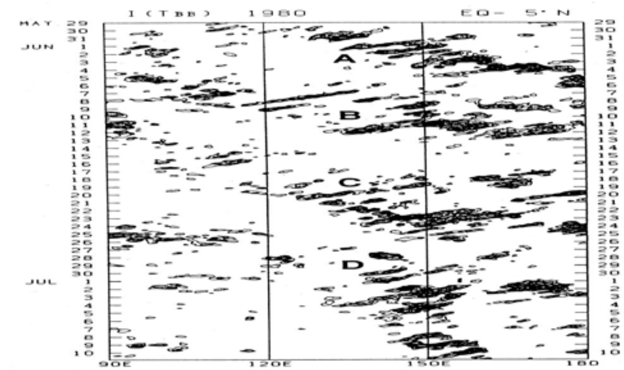
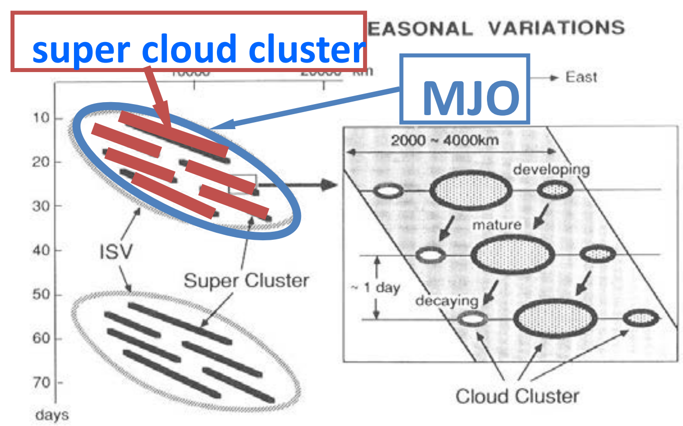


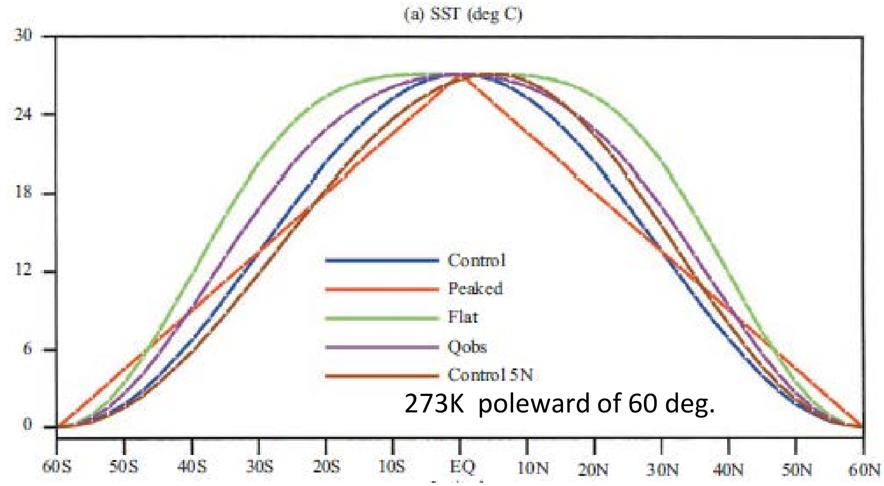

Fig. 2. Time-longitude section of TBB index ($I_{TBB}$) integrated between the equator and 5°N obtained from the 3-hourly GMS IR data from 29 May 00Z to 10 July 21Z, 1980. Symbols A to D denote the same super cluster as in Fig. 1. Contour interval is 10, and shading denotes the region where values are greater than 20.



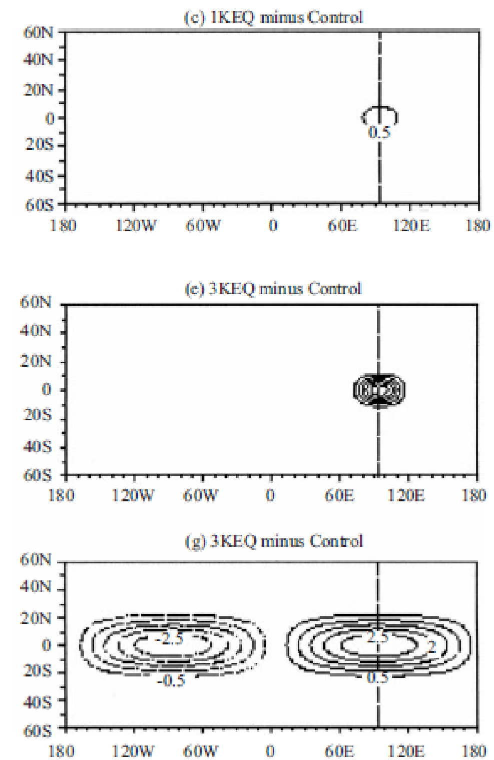

Schematic diagram for hierarchy of ISV. (Nakazawa, 1988)

# The APE project

APE Aqua-Planet Experiment Project




**Proposal : Neale and Hoskins (2000a,b)**
**Numerical Experiments Performed: 2003-2006**
**Workshops: 2005@Reading UK, 2007@Choshi JP**
**Results: APE ATLAS (2011), JMSJ Special Issue (2011)**




Idealised climates simulated by AGCMs which are being used and developed for NWP and climate research.

Several idealised distributions of SST, focusing on
- the distribution and variability of convection in the tropics
- the storm-tracks in mid-latitudes.

A benchmark of current model behavior
Understand the causes of inter-model differences
subgrid-scale parameterization suites,
dynamical cores, resolution

14 groups from 6 countries + ECMWF

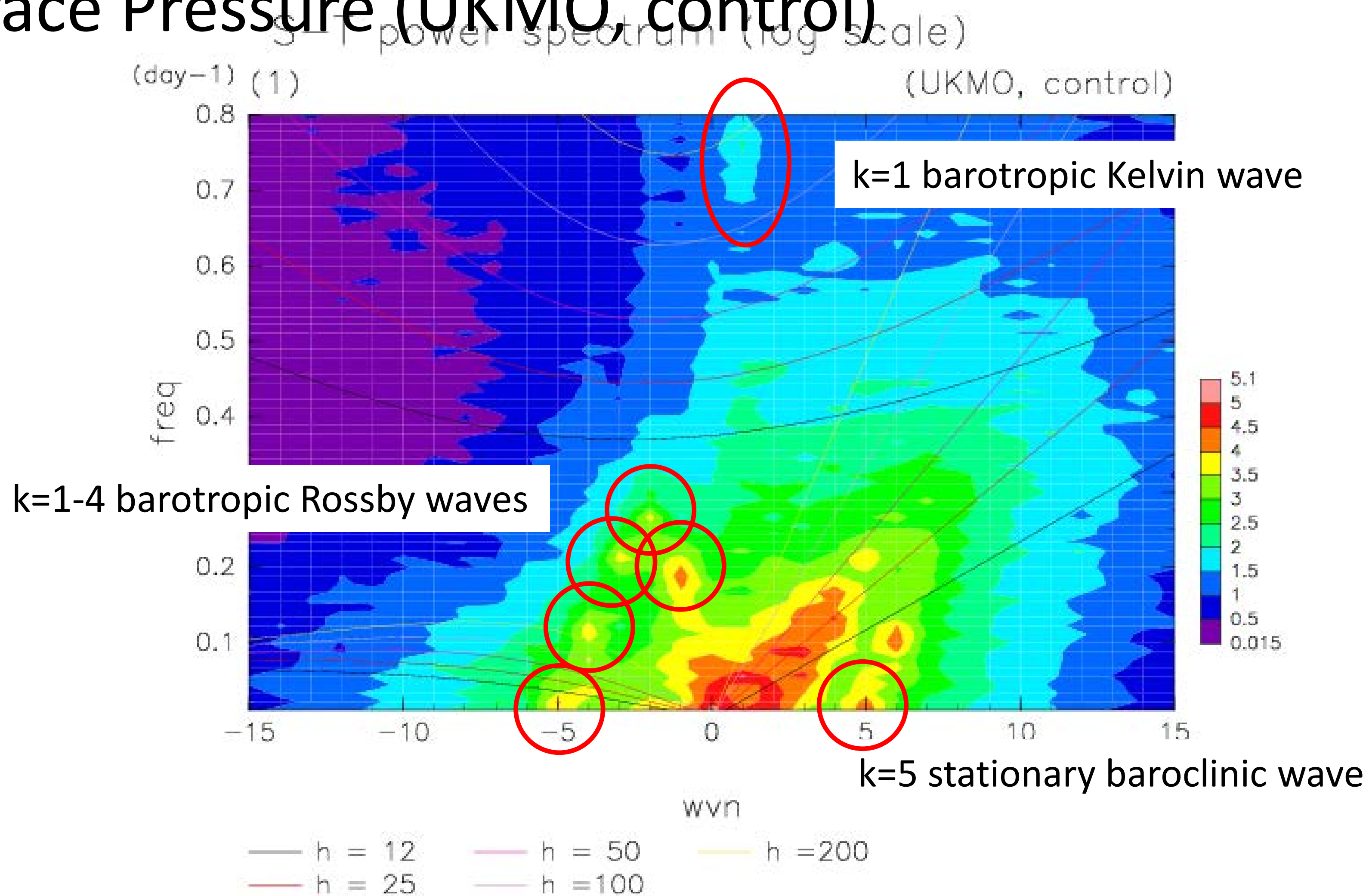
| Group-ID | Resolution, | Dynamics, horizontal | Deepconvection |
|---|---|---|---|
| AGUforAPE | T39L48 (3x3) | Spectral | Emanuel (1991) |
| CGAM | 2.5 x 3.75 L30 | Arakawa B grid | Gregory-Rowntree penetrative mass-flux convection |
| CSIRO (standard) | C48 L18 (2x2) | Conformal cubic grid | Mass flux type with downdraft |
| CSIRO (old) | C48 L18 (2x2) | Conformal cubic grid | Mass flux type with downdraft |
| DWD | ni=64 L31 | icosahedral grid | Bulk mass flux (Tiedke, 1989) |
| ECMWF | T159L60 (2x2) | Spectral | Bulk mass flux (Tiedke, 1989) |
| ECMWF_07 | T159L60 (2x2) | Spectral | Bulk mass flux (Tiedke, 1989) |
| FRCGC | 7km mesh (0.063x) | Icosahedral grid | Cumulus (partial) resolving |
| GSFC | 2 x 2.5 L34 | 4th order global grid | Relaxed AS (Moorthi &Suarez, 1992) |
| GFDL | ? | ? | Relaxed AS |
| K-1 Japan | T42L20 (2.8x2.8) | Spectral | Prognostic AS (Pan &Randall, 1998) |
| LASG | R42L9 (2.8x2.8) | Spectral | Slingo cloud parameterization scheme, Manable convective parameterization |
| MIT | ? | ? | Relaxed AS (Moorthi &Suarez, 1992) |
| MRI | T42L30 (2.8x2.8) | Spectral | Prognostic AS |
| NCAR | T42 L26 ? (2.8x2.8) | Spectral | Zhang and McFarlane (1995) |
| UKMO_n48 | N48L38 (2.5x3.75) | Arakawa C grid | Gregory-Rowntree |
| UKMO_n96 | N96L38 (1.25x1.625) | Arakawa C grid | Gregory-Rowntree |

See "APE ATLAS" Williamson et al (2012) for details.

# NOTABLE FEATURES FOUND IN APE OWING TO IT'S IDEALIZED SET-UP

# Normal Modes easy to identify

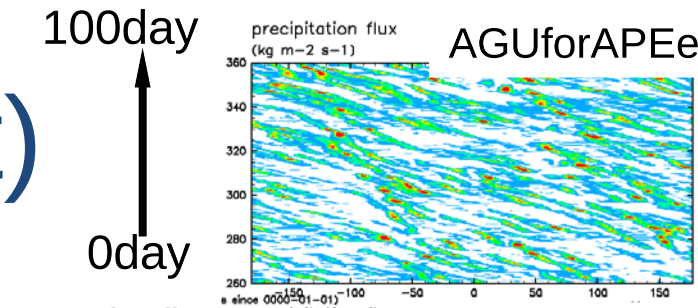
## Example1: “raw” Wavenuber-Frequency Spectrum of Surface Pressure (UKMO, control)

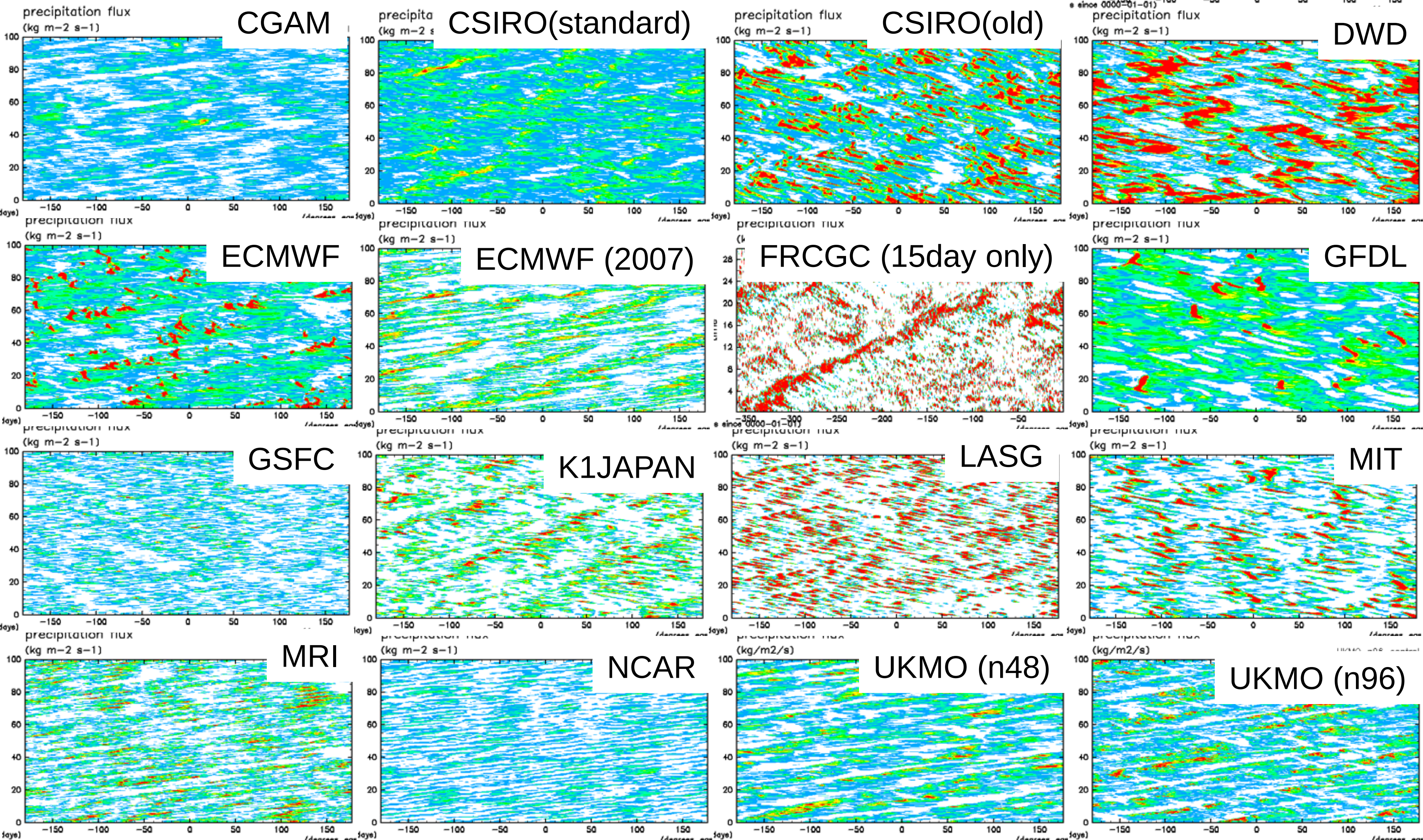


**EXAMPLE OF COMPARISON (ZONALLY UNIFORM SST)**

**DIVERSITY OF TROPICAL CONVECTIVE ACTIVITY**

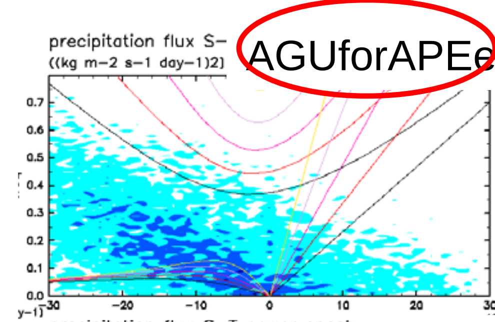
# Precipitation at EQ (x,t)

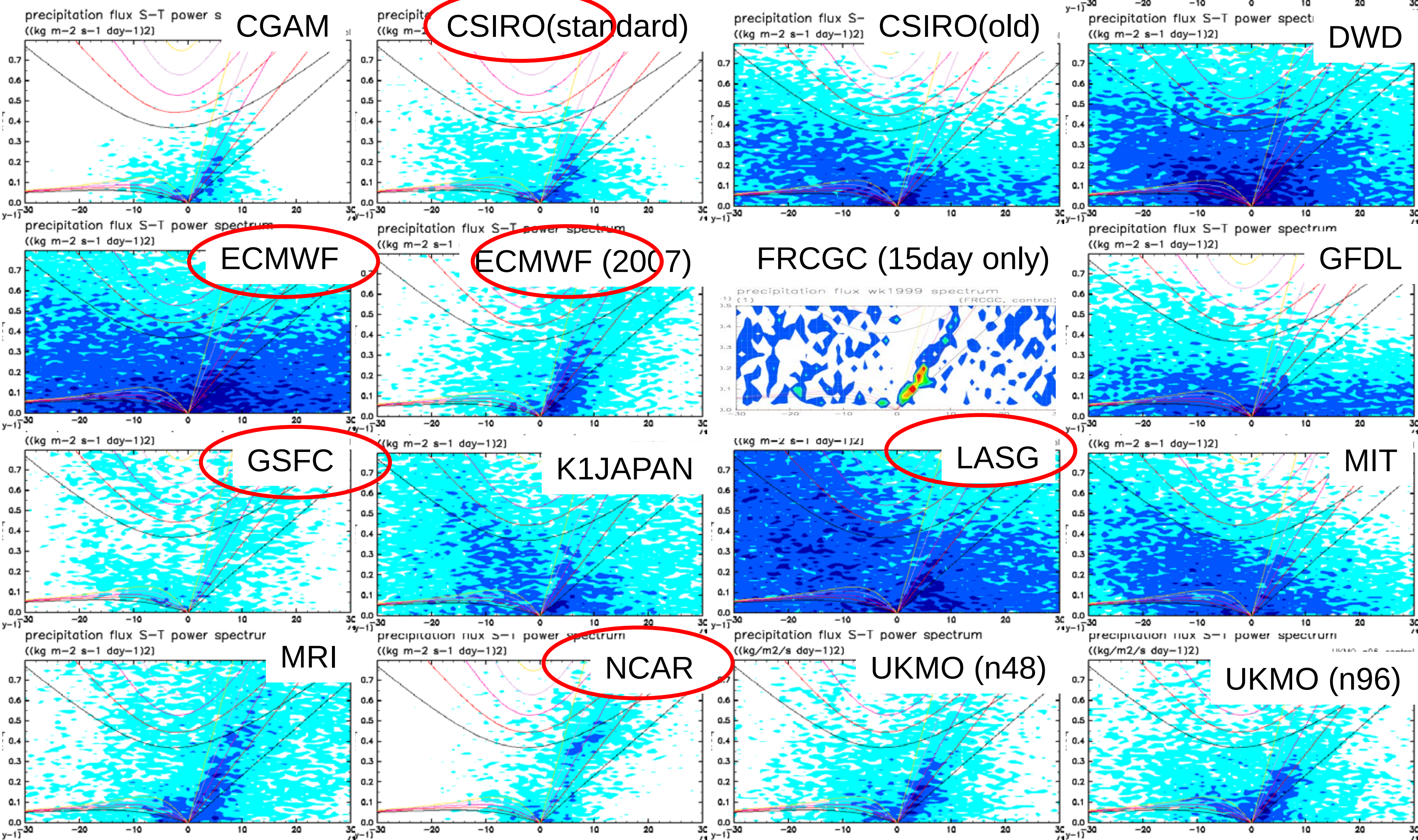


# Precipitation Spectra

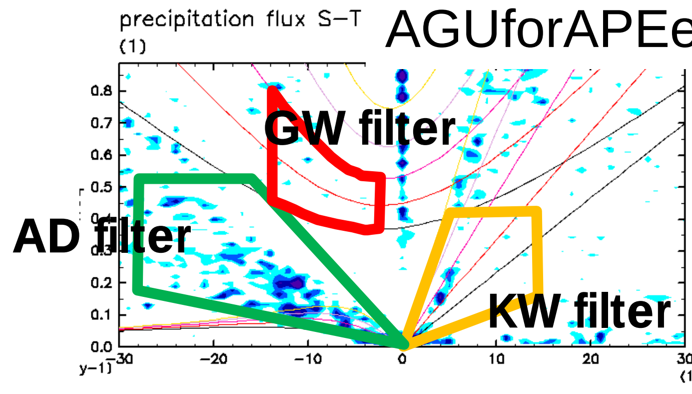
Kelvin wave like signal can be found in most models.

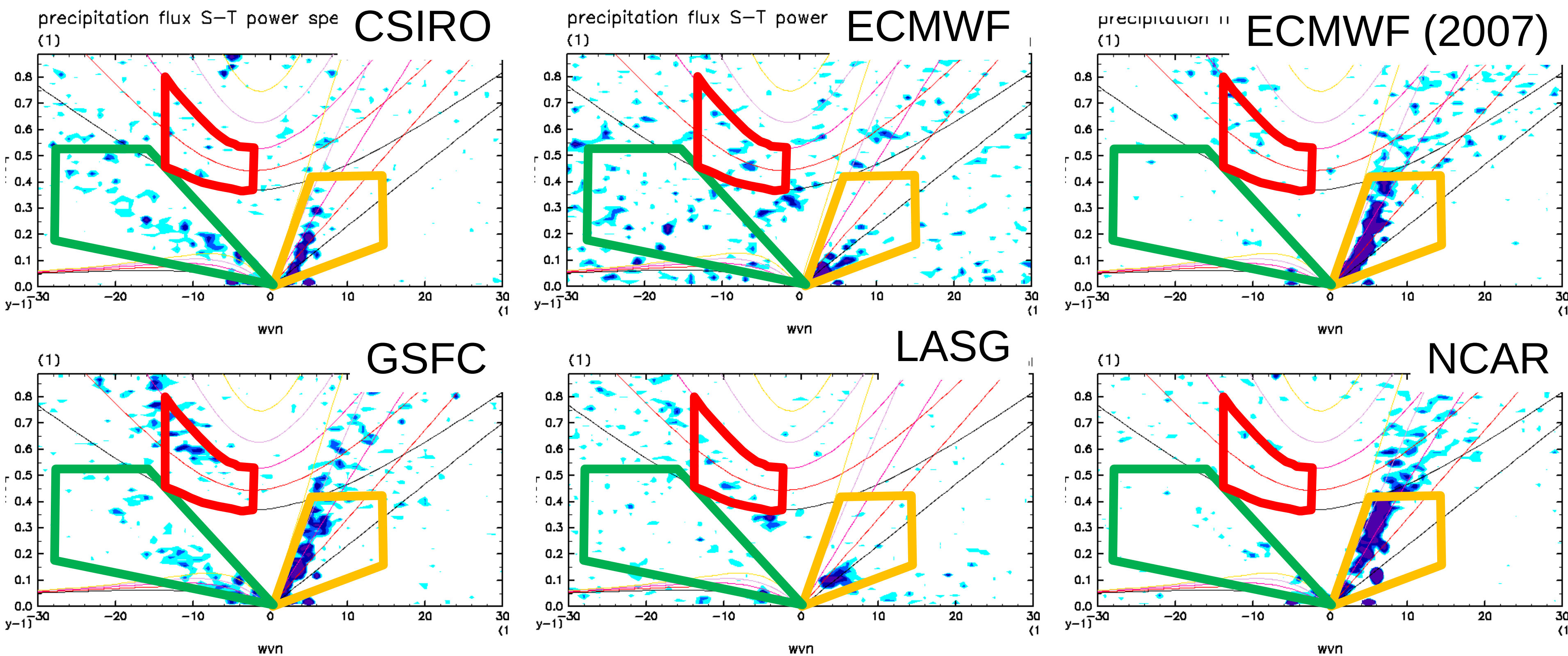


# Spectral filters defined from Wheeler & Kiladis plots

KW filter : Kelvin wave signals
GW filter : westward gravity wave signals
AD filter : “advective” signals

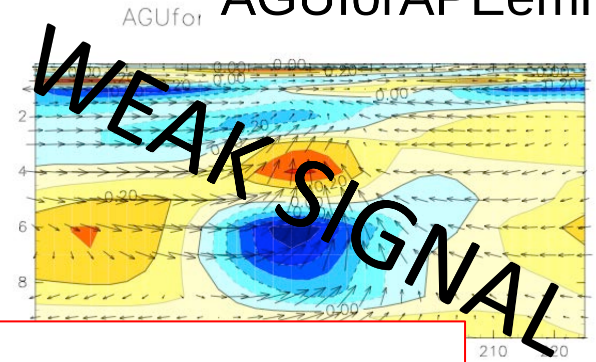


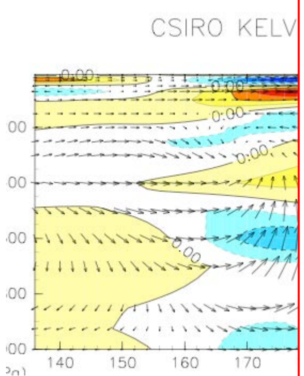



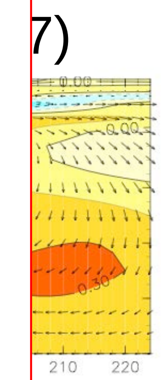
# KW filter / composite [ T, (u, omg) ]

Westward phse tilt? … Probably.

ECMWF(05/07) and LASG.
 Westward phase tilt is evident (wave-CISK like).
GSFC : Eastward tilt
AGUforAPE: cold upward motion

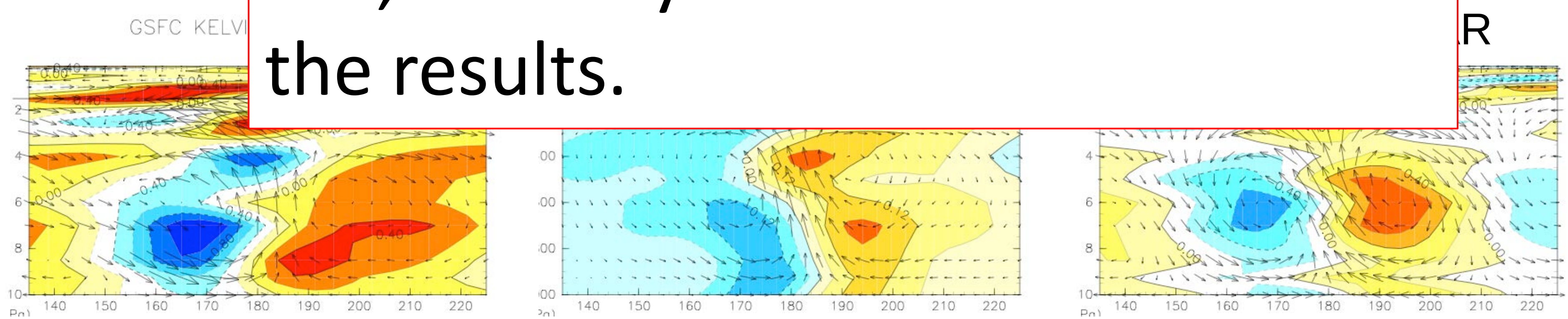



You may want to know
why these difference develop.

But, it is very difficult to understand
the results.

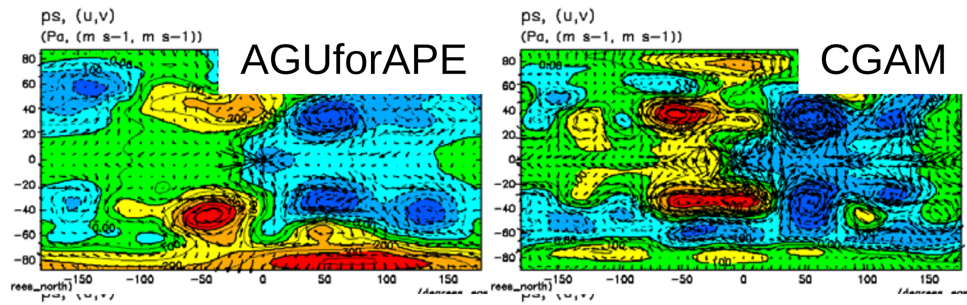


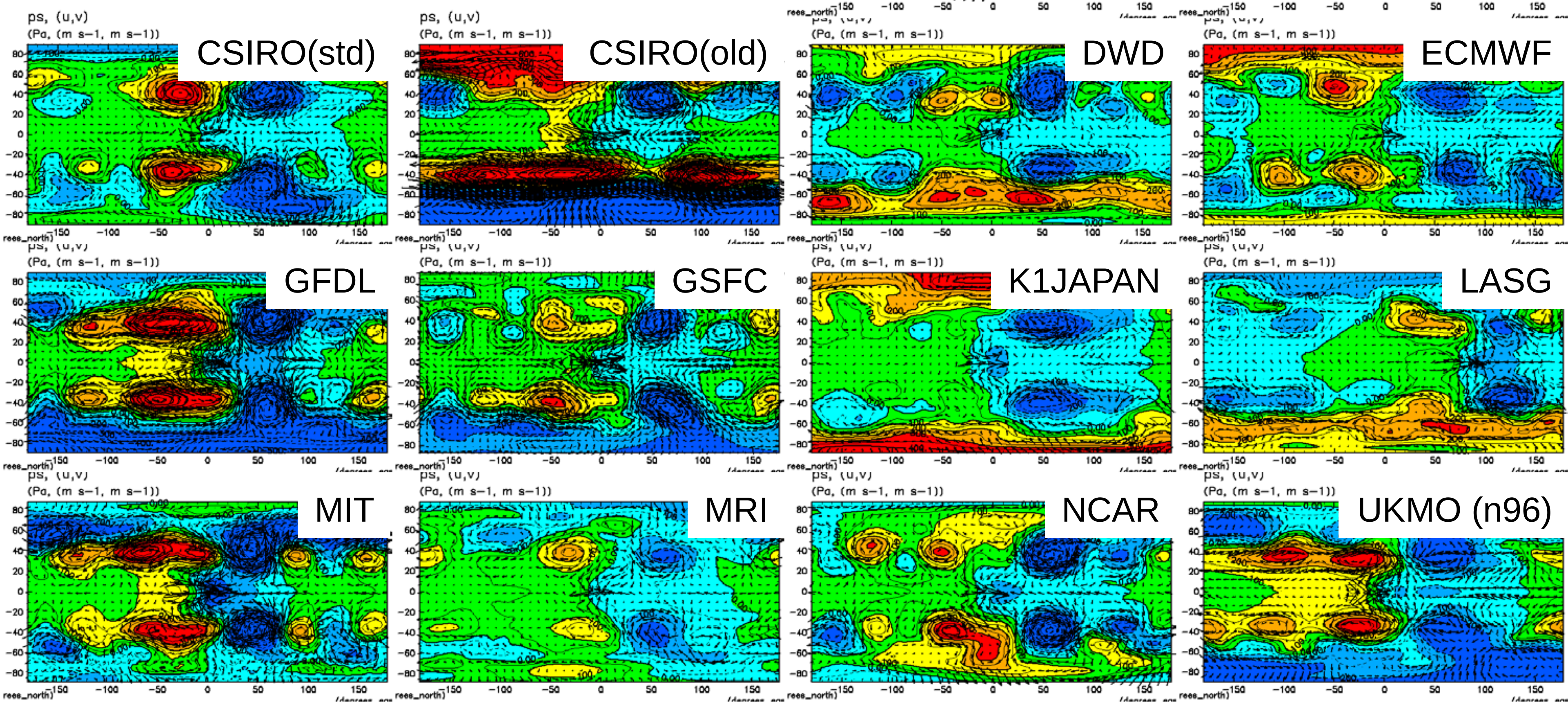
**EXAMPLE OF COMPARISON**
**( WITH SST ANOMALY)**

**RESPONSE TO SST ANOMALY IS VERY “STRANGE”.**

# Surface pressure and wind (3keq)

The intensity of
mid latitude Rossby response
diverges considerably.



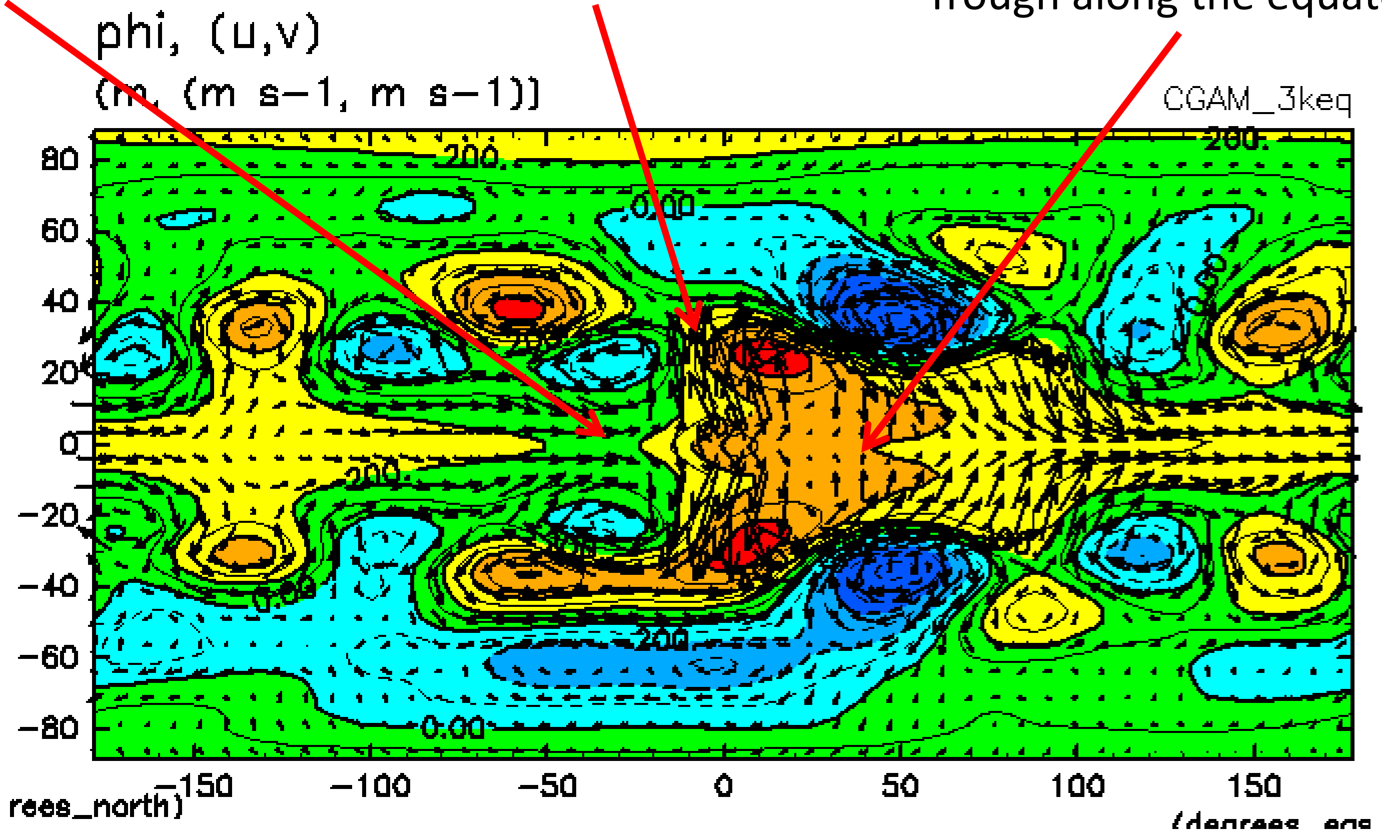



# Significant difference from classical Matsuno-Gill pattren

No westward outflow.

Poleward outflow

No eastward outflow.
Trough along the equator.

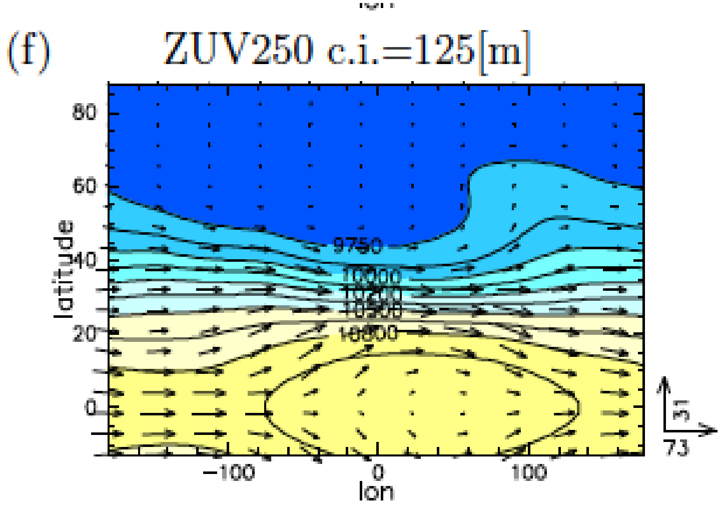


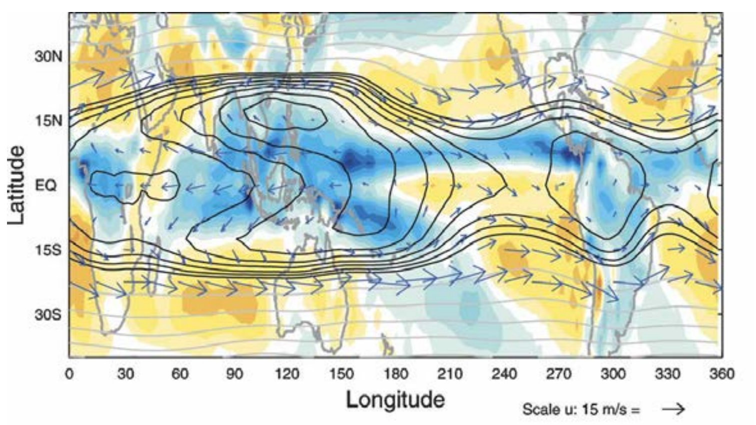

upper tropospheric response (CGAM)

# 3KW1 vs "Walker circulation"

In APE,
high pressure
develops
to the east of
warm SST area.

In the real atmosphere,
high pressure develops
to the west of
warm SST area.

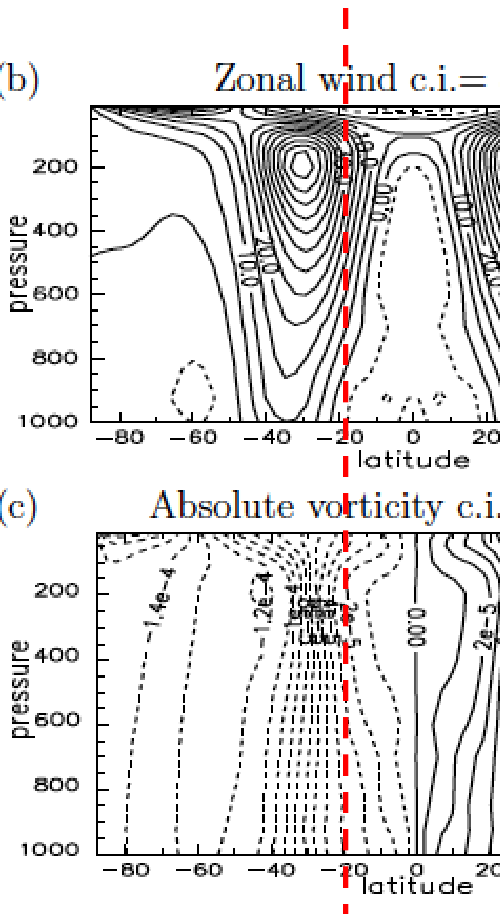


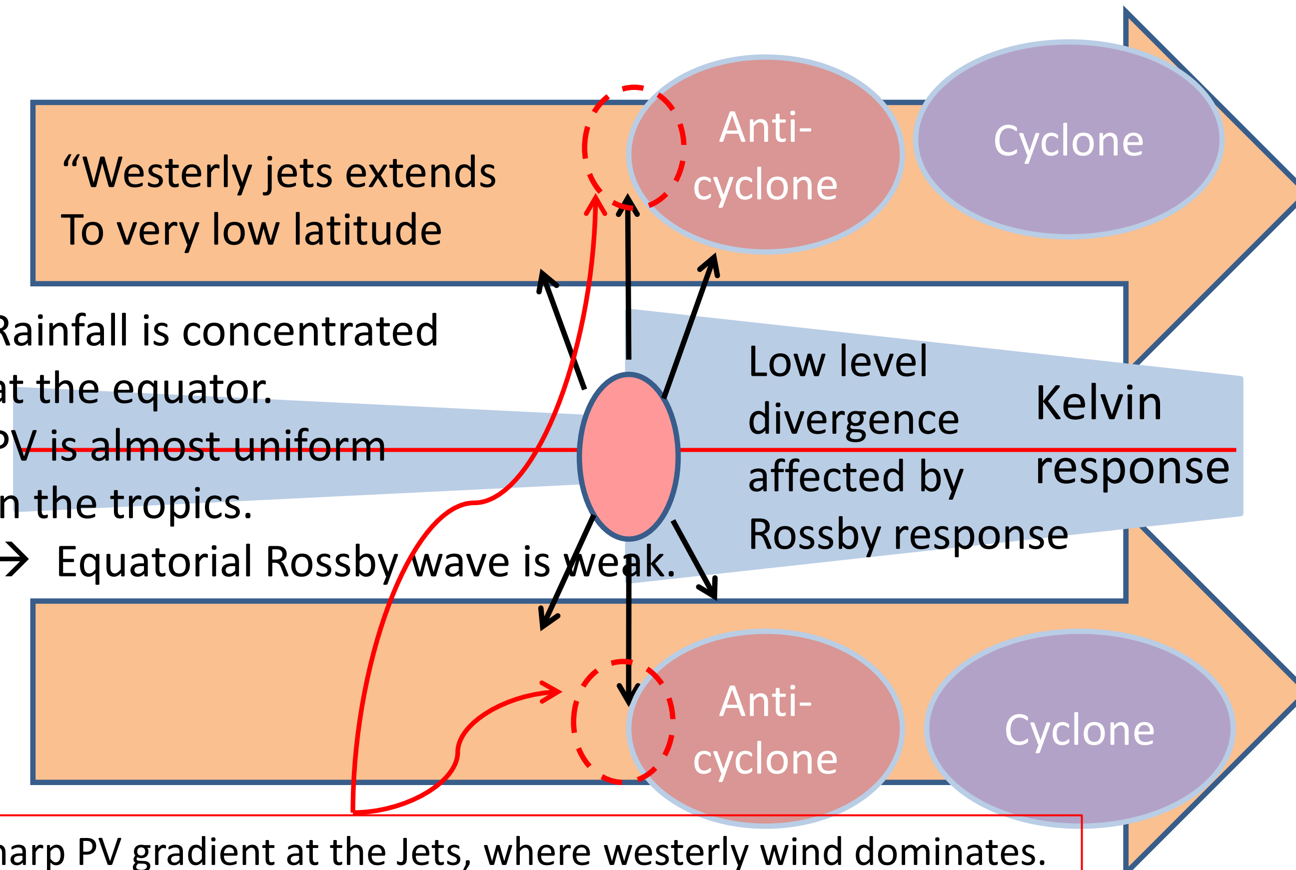




upper tropospheric pressure and wind fields

# Why is the response in APE strange?

Zonal mean state
obtained in APE
is not so realistic.




Rainfall is concentrated
at the equator.
PV is almost uniform
in the tropics.
→ Equatorial Rossby wave is weak.

Sharp PV gradient at the Jets, where westerly wind dominates.
Anticyclonic vorticity source due to PV advection
by the divergent wind from convection center.
(Cf. Saradeshmukh and Hoskins, 1988)

# Retrospect on APE

- APE as Idealized experiments
  - Simple set-up allows clear display of “waves” and their mutual interaction.
    - Interpretation, however, is not necessarily easy.
  - It is not easy to choose or justify setup
    - Apparently subtle difference in set-up can result in large difference.
    - Compromize between “reality” and “idealization”
- APE as an intercomparison project
  - Variety among results from different models is VERY DIVERSE.
    - Interpretation, again, is not necessarily easy. To help it, we need
      - Enough data (variables, space-time coverage/resolution)
      - Enough description of participating models (source codes?)
      - Cooperation among modelers, theoreticians, and data-analysts

# Concluding remarks

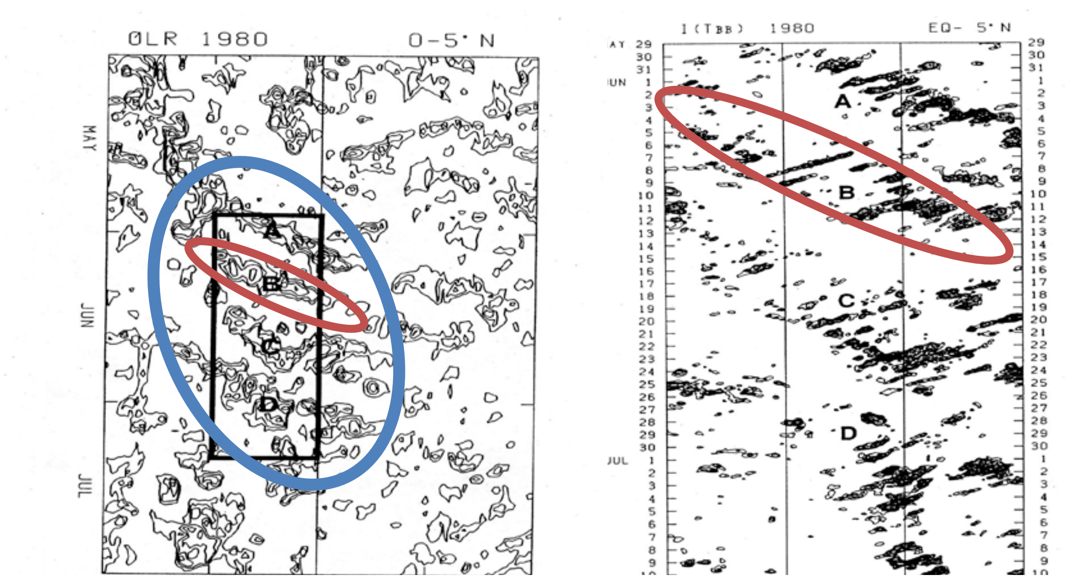
- Aqua planet is not easy to understand.
  - Aqua Planet setup is one of the most serious test beds of AGCMs.
- Necessity and possibility of "APE2"?
  - More complete data should be collected.
  - Advancement since 2005 may improve convergence of results.

Thank you for your attention!

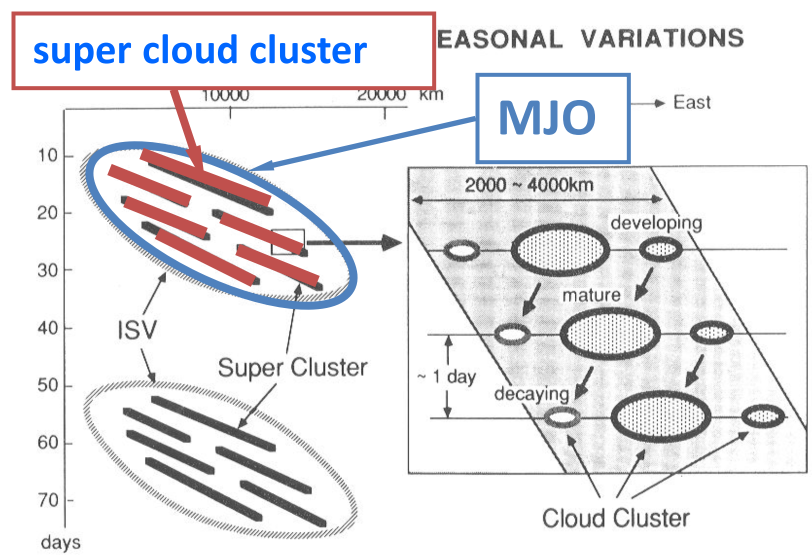
# Background

## Equatorial hierarchical structure of precipitation activity

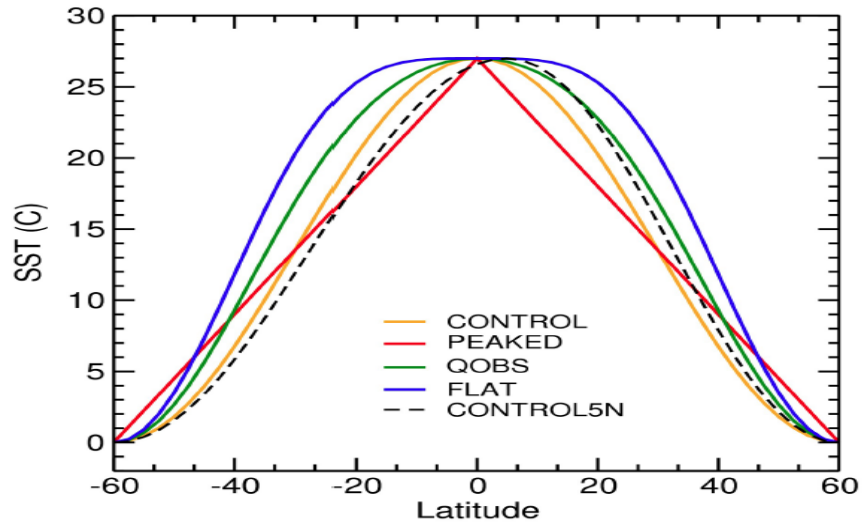
- It has been argued that there exists three types of structure with different time and spatial scales; MJO, super cloud cluster and cloud cluster.
- The representations in GCMs differ model  by model.



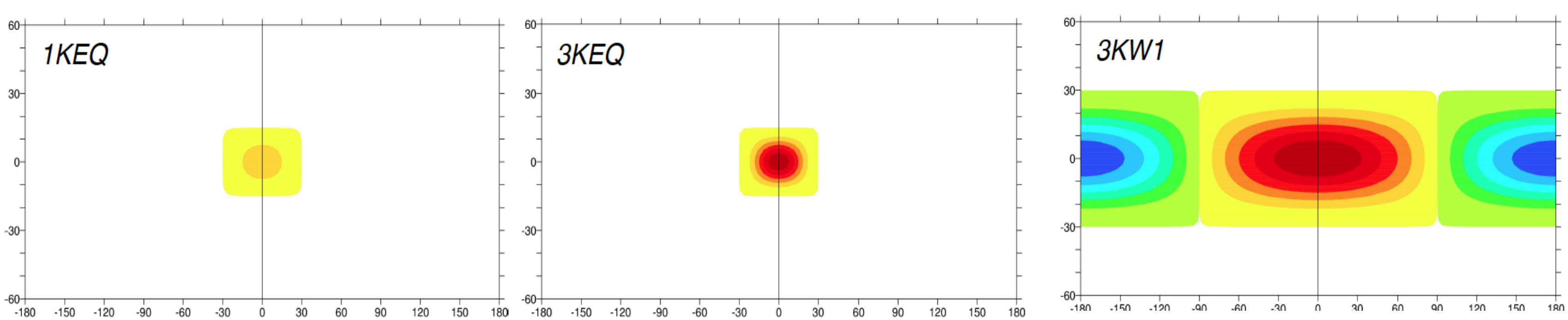

Time-longitude section of transient OLR averaged between the equator and 5N from May to July in 1980. (Nakazawa, 1988)




Schematic diagram for hierarchy of ISV. (Nakazawa, 1988)

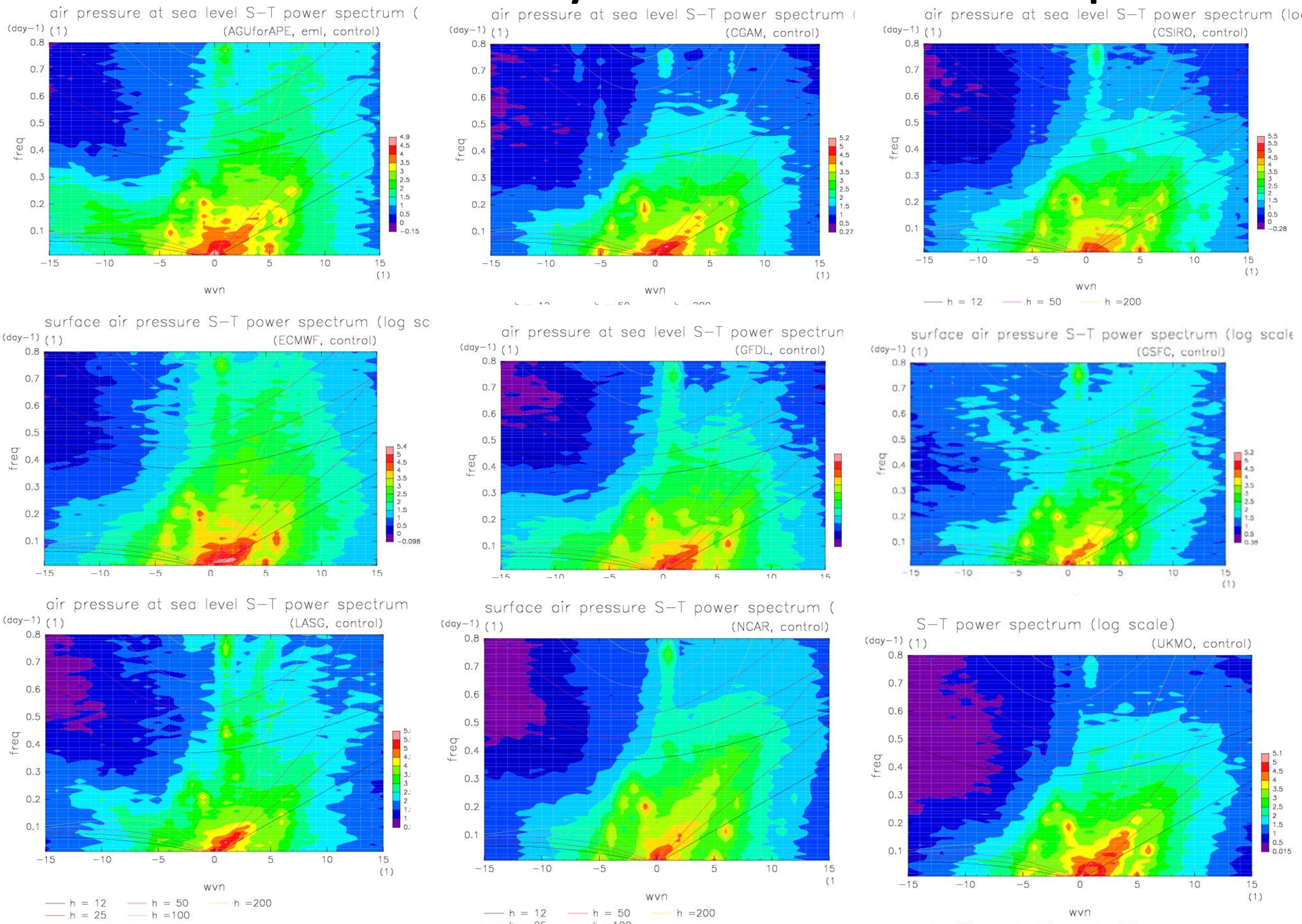


SST (C)
Latitude
CONTROL
PEAKED
QOBS
FLAT
CONTROL5N

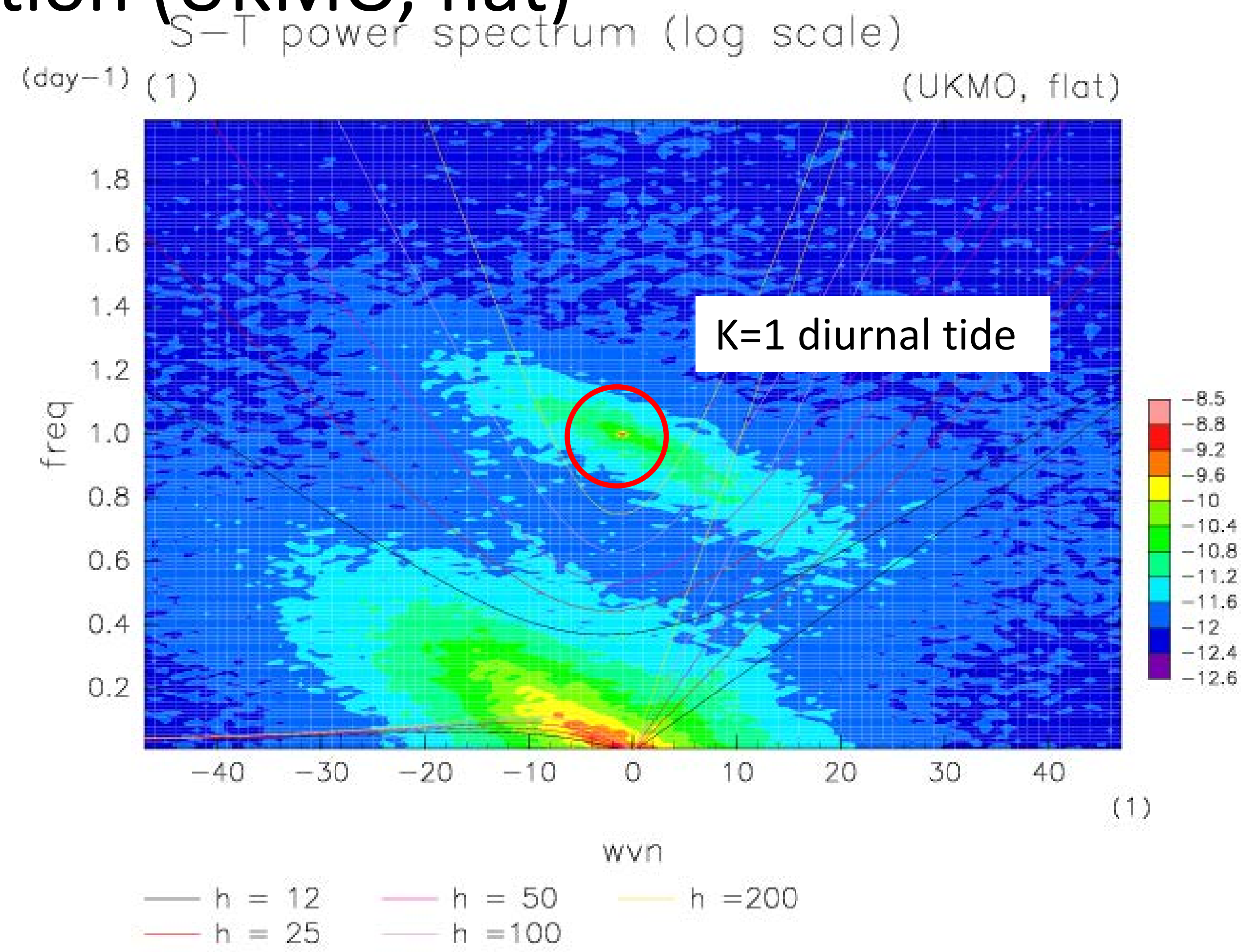
1KEQ
3KEQ
3KW1

# Normal Modes maybe useful for comparison



# Normal Modes easy to identify

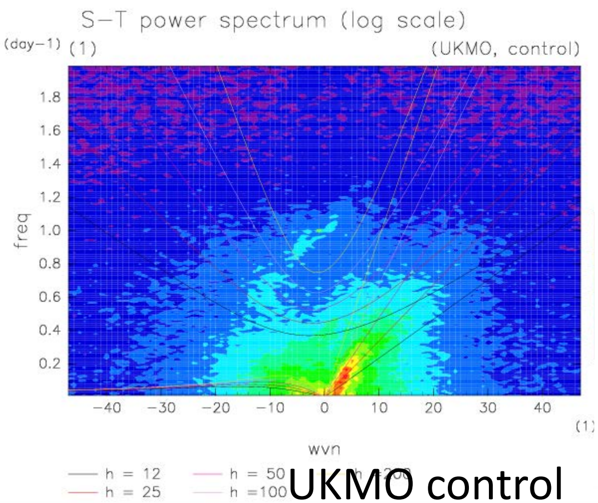
Example2: “raw” Wavenuber-Frequency Spectrum of Precipitation (UKMO, flat)



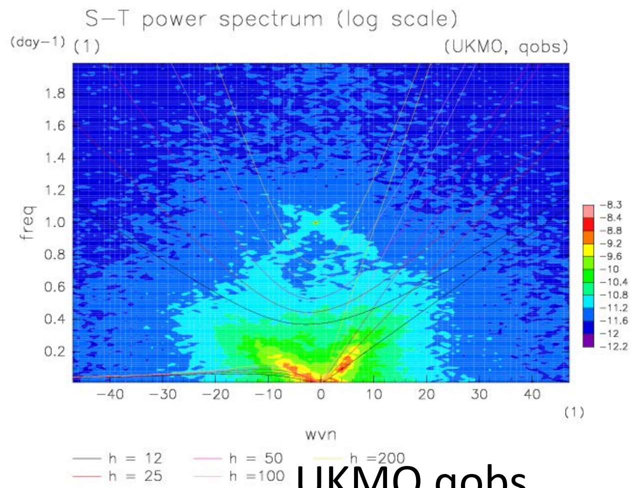
# Signal Modulation easy to identify

## Example3: Spectrum of Precipitation

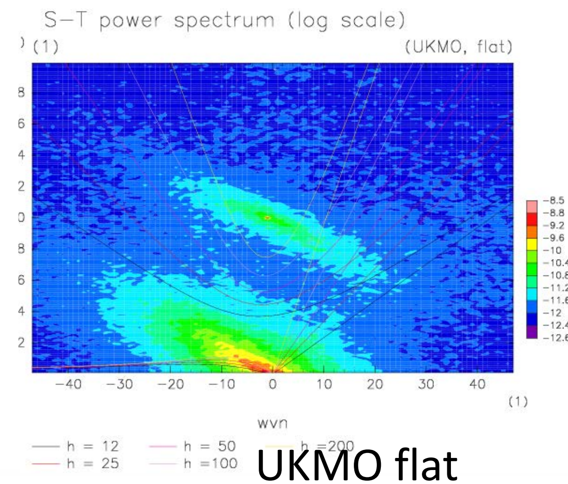
## Modulation of Tropical Signals by Atmospheric Tide




UKMO control




UKMO qobs




UKMO flat

Product of two waves in real space <-> sum in wavenumber space

$\exp[i(k_1x-f_1t)] * \exp[i(k_2x-f_2t)] = \exp[i\{(k_1+k_2)x-(f_1+f_2)t\}]$

Product with diurnal tide

<-> shift of (k,f) → (k-1 , f + (1/1day) )

Note they are NOT "inertio gravity waves".

# APE RESULTS

- No model is similar to others.
- Because of it's simple set up,
  we can safely identify that the difference is caused by model implementation of the atmosphere, not from the surface inhomogeneity.
  APE is a good (tough) tool of model intercomparison.
- However, it is not very easy to understand what is going on, how they are different, …

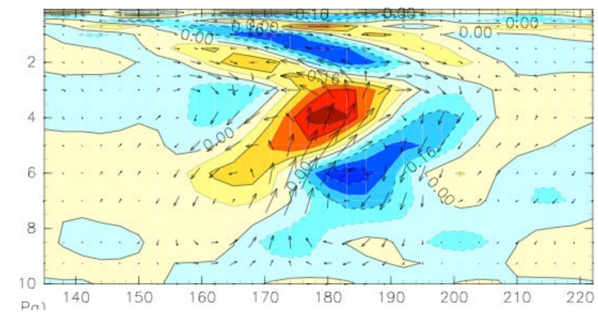
Let us try spectral analysis  to identify possible disturbance structures

# GW filter / composite [ T, (u, omg) ]

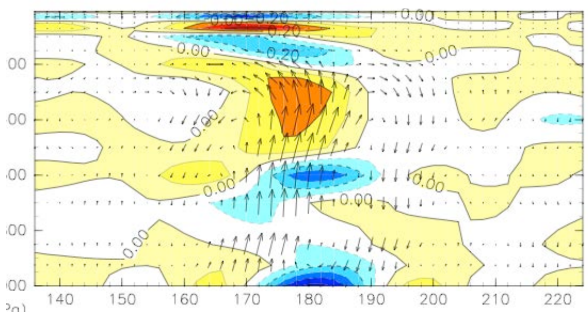
Eastward phase tilt? … Probably.

ECMWF05 and LASG:
  Eastward phase tilt is evident  (wave-CISK like).
GSFC: strong power  but …

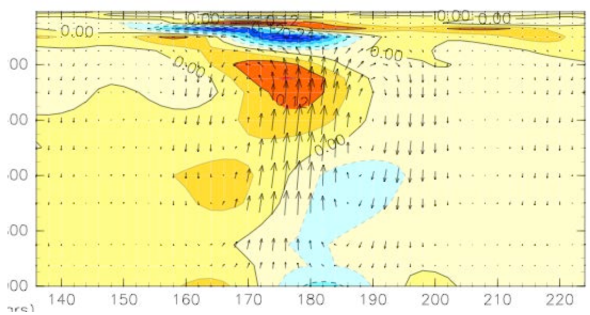
AGUforAPE (  AGUforAPEe



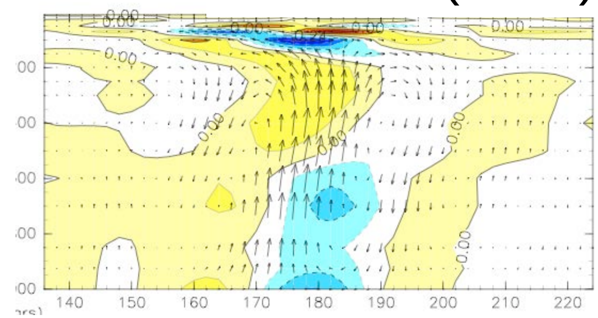
CSIRO GRAV T(U,–  CSIRO



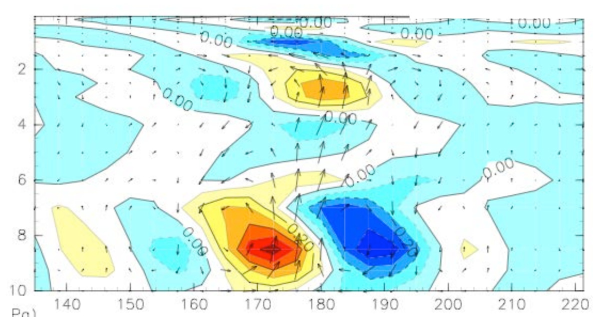
ECMWF GRAV T(U  ECMWF



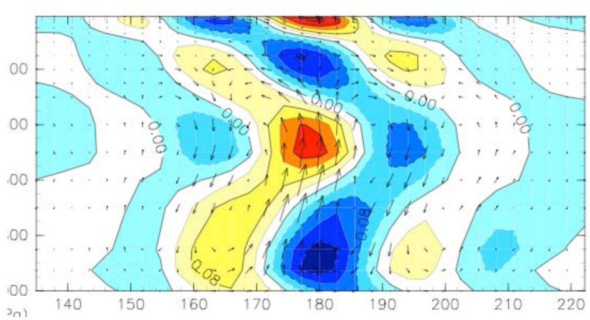
ECMW  ECMWF (2007)



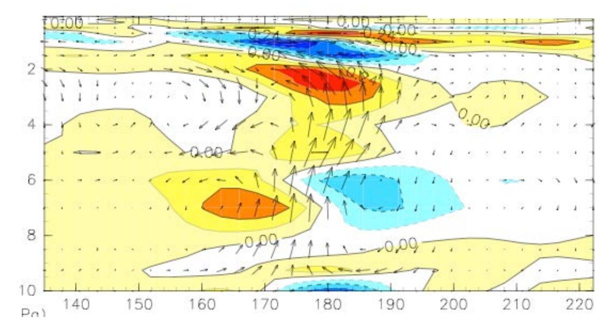
GSFC GRAV T(U,–OI  GSFC



LASG GRAV T(U,–OM(  LASG

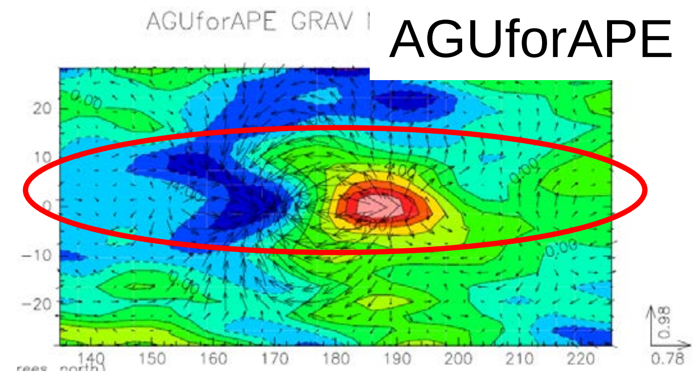


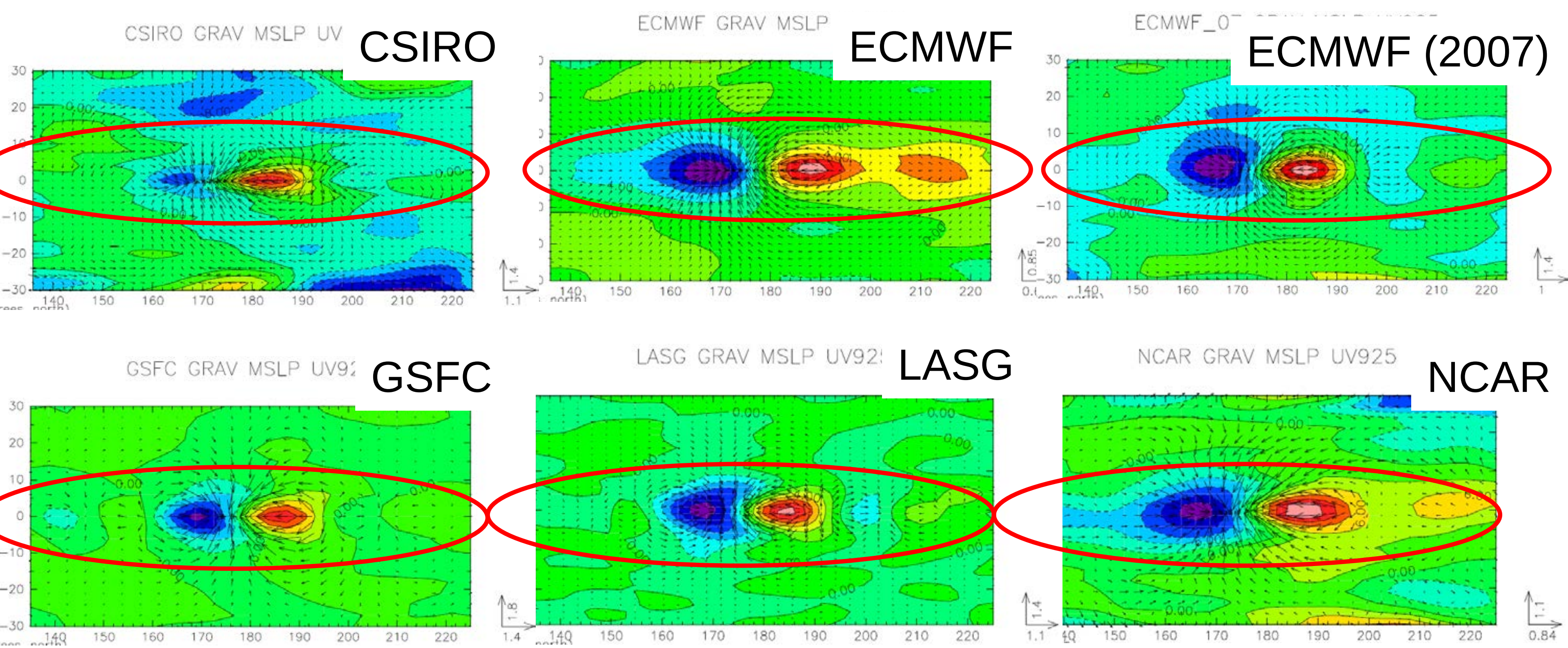
NCAR GRAV T(U,–OI  NCAR



# GW filter / composite [mslp,uv925]

More or less n=1 westward inertio gravity wave like.

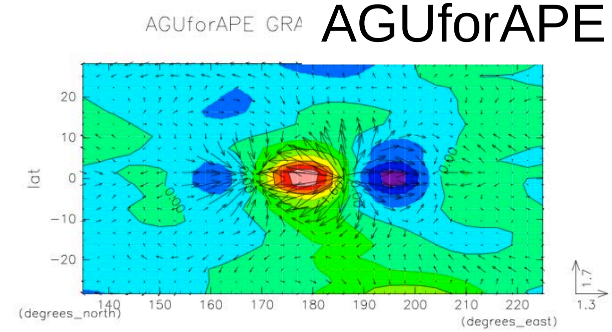


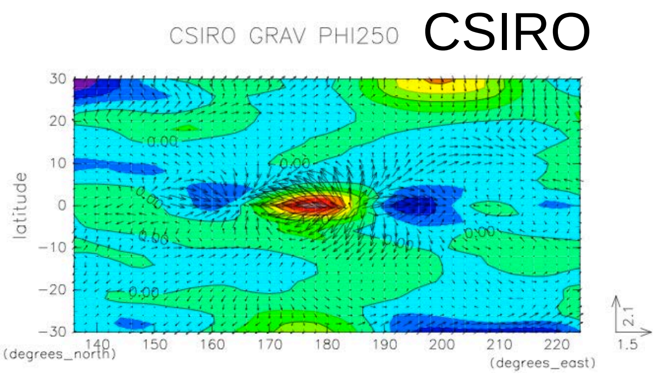



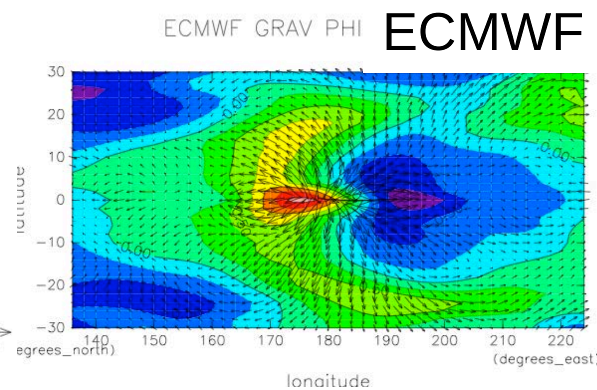
# GW filter /composite [phi,u,v250]

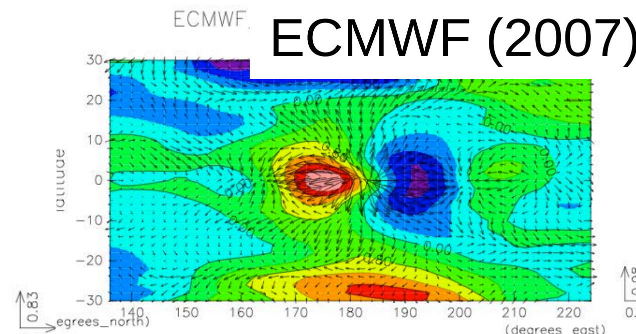
More or less GW-like.
All are similar.

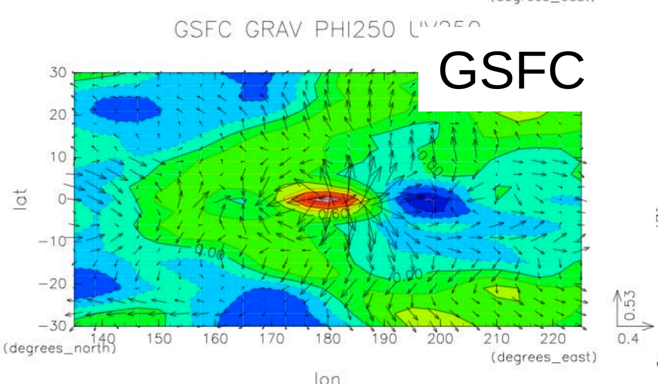
Because c-U is large,
Not affected by U.

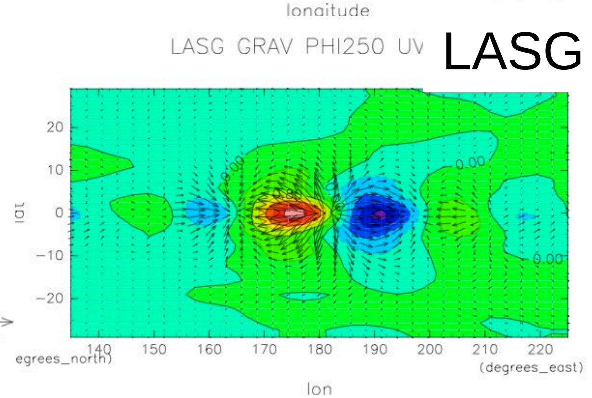


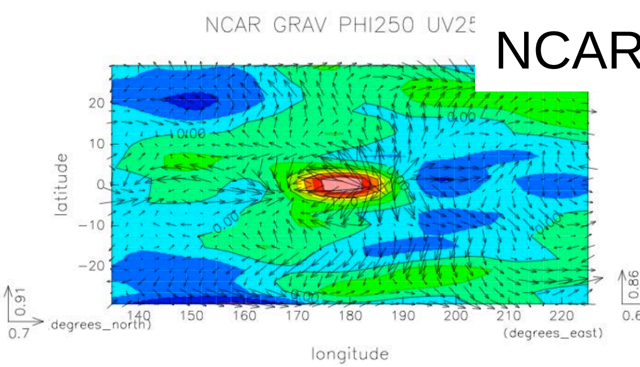



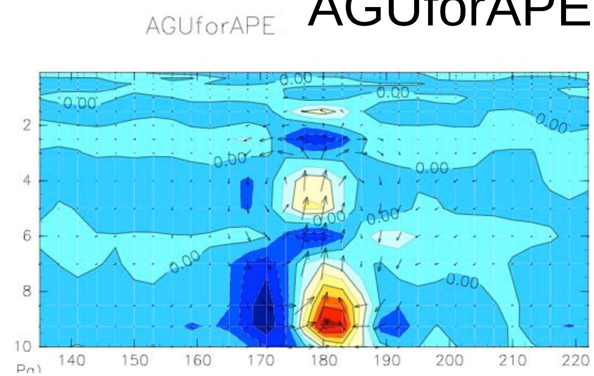



# AD filter / composite [ T, (u,omg) ]

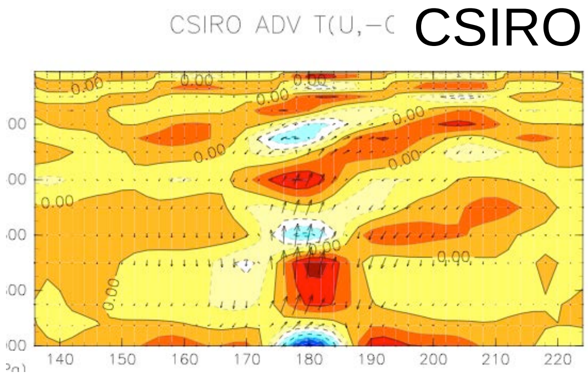
No phase tilt?

Vertical structure displays significant variety:
Vertical structure of T suggests complex
structure of heating (downdrafts, ice phase etc.)

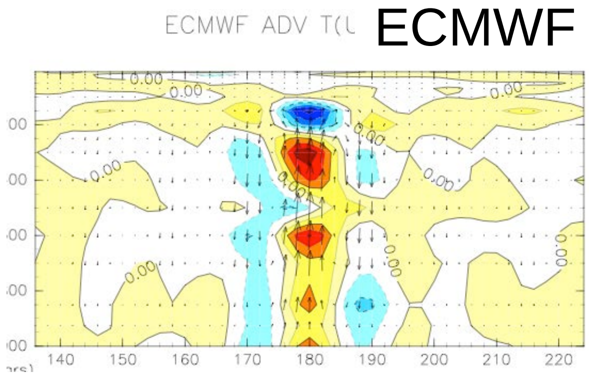
AGUforAPEe



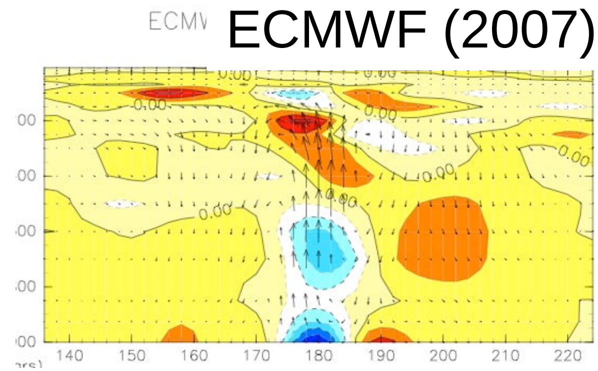

CSIRO



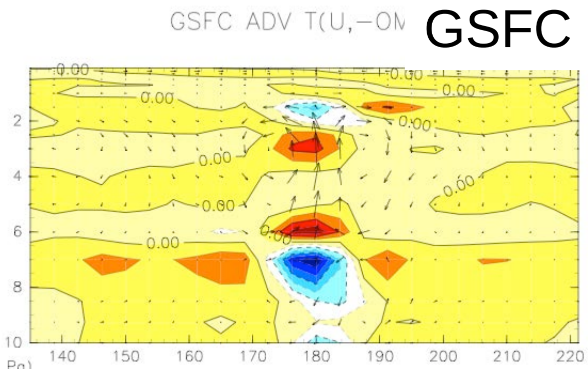

ECMWF



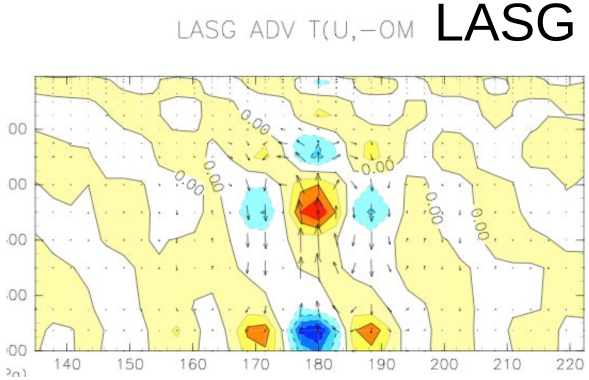

ECMWF (2007)



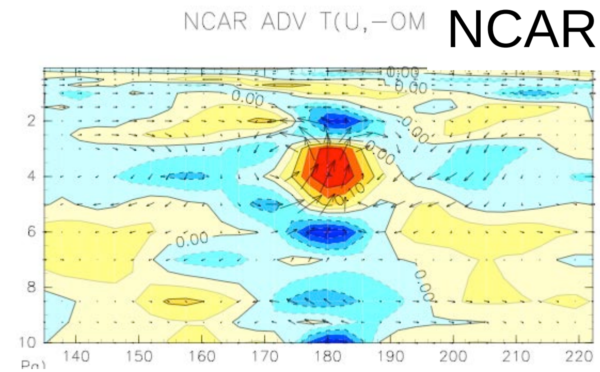

GSFC




LASG

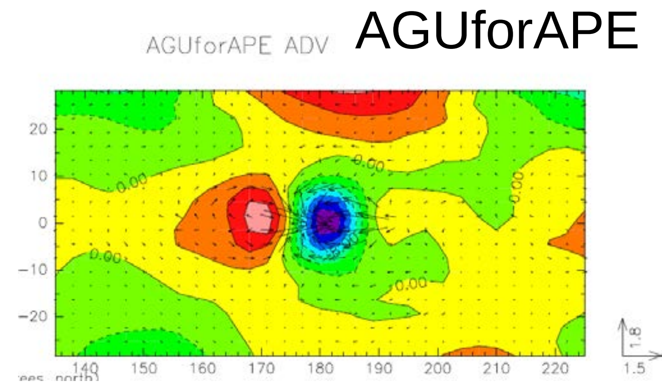


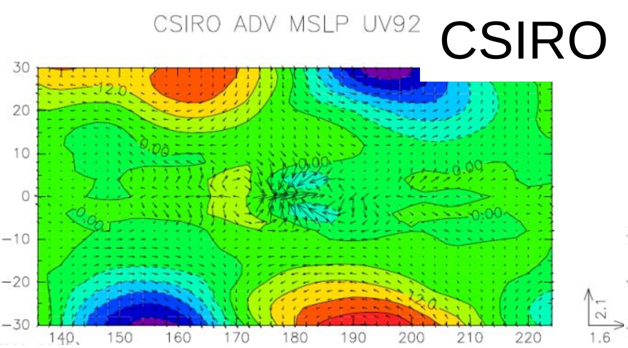

NCAR

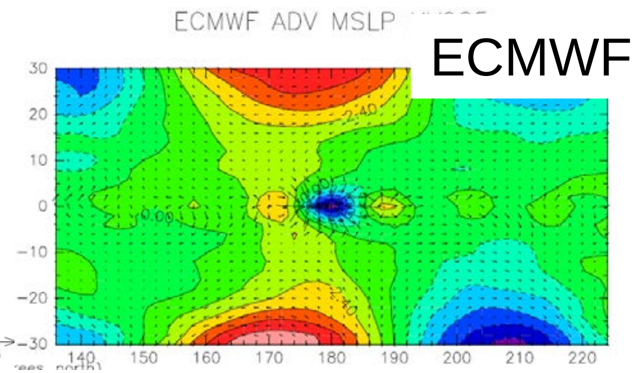


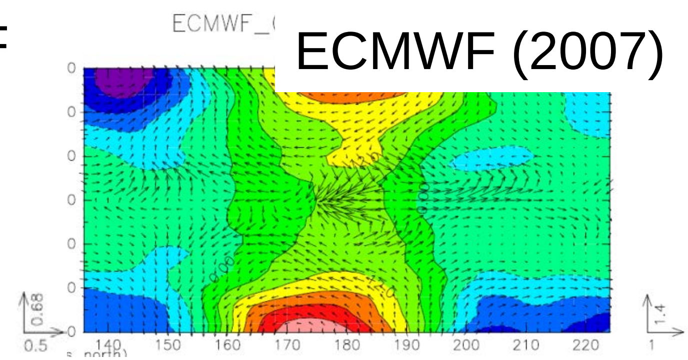
# AD filter / composite [mslp,uv925]

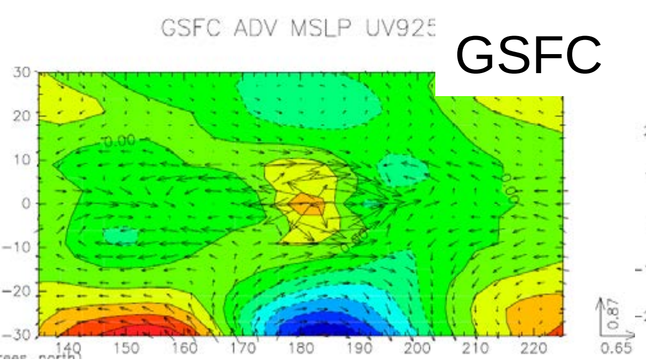
Horizontal structure displays significant variety.

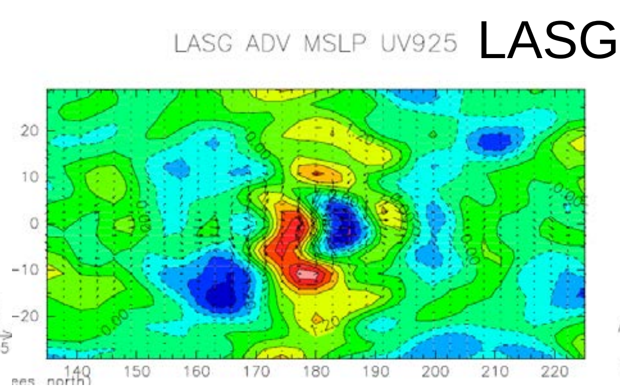


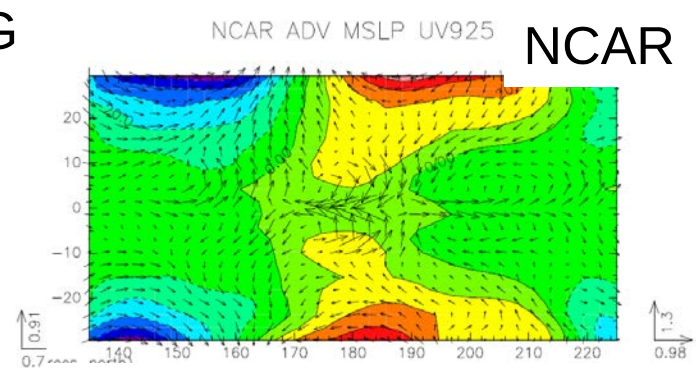



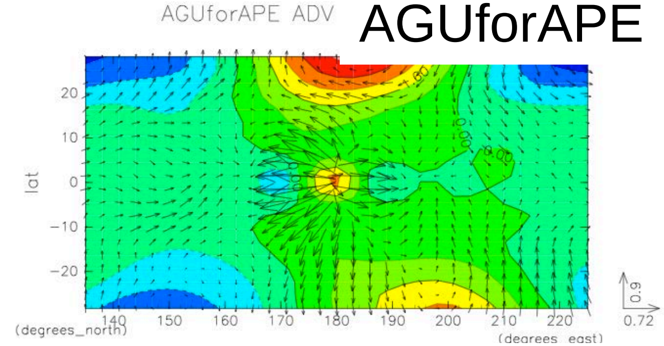



# AD filter /composite [phi,u,v250]

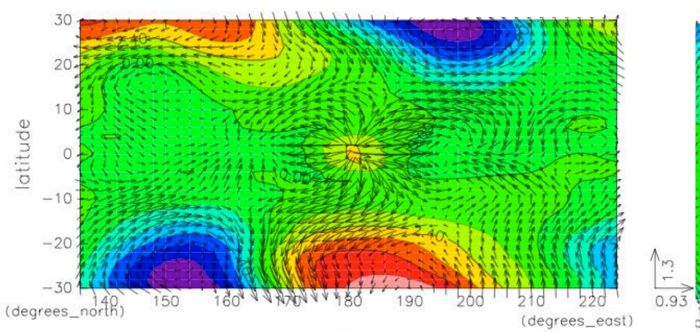
More or less GW-like.
All are similar.

Because c-U is large,
Not affected by U.

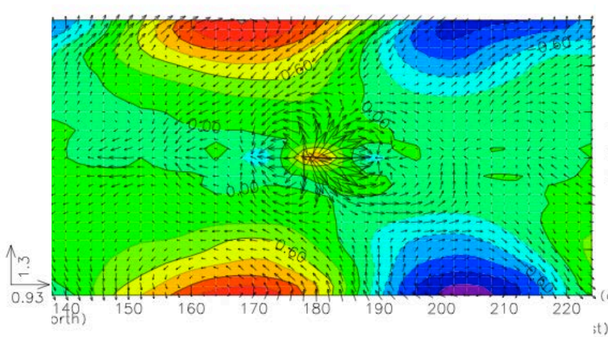
AGUforAPE



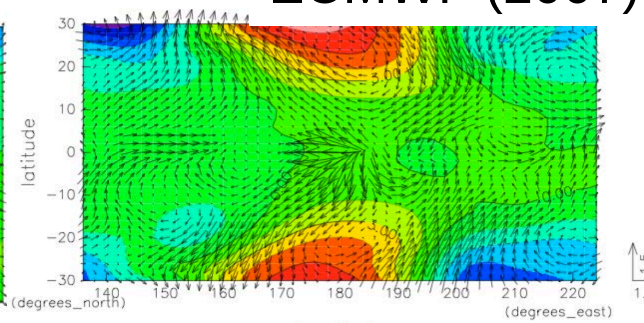

CSIRO



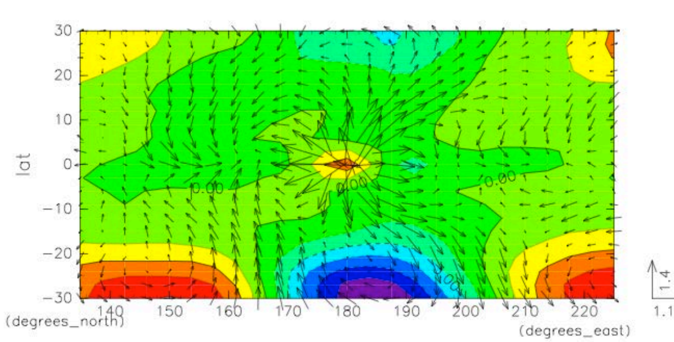

ECMWF



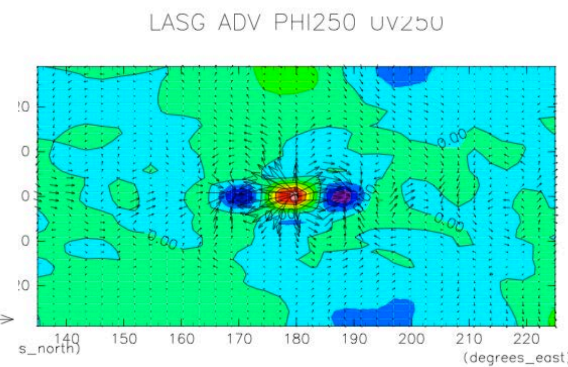

ECMWF (2007)



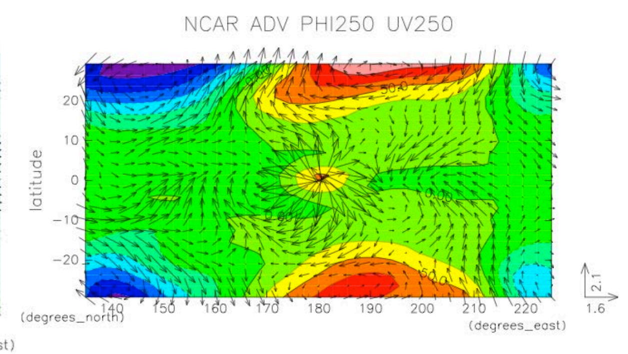

GSFC



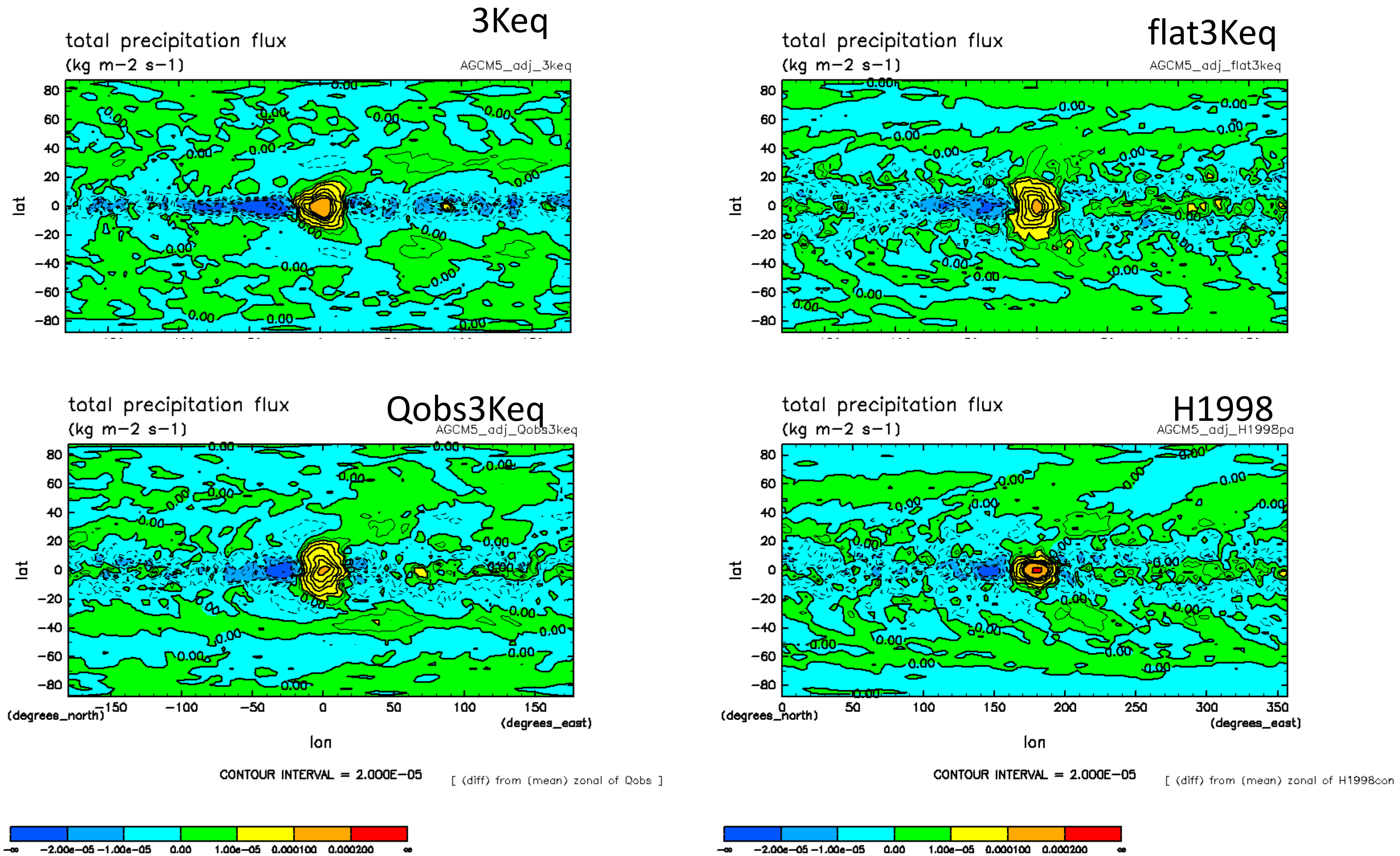

LASG




NCAR



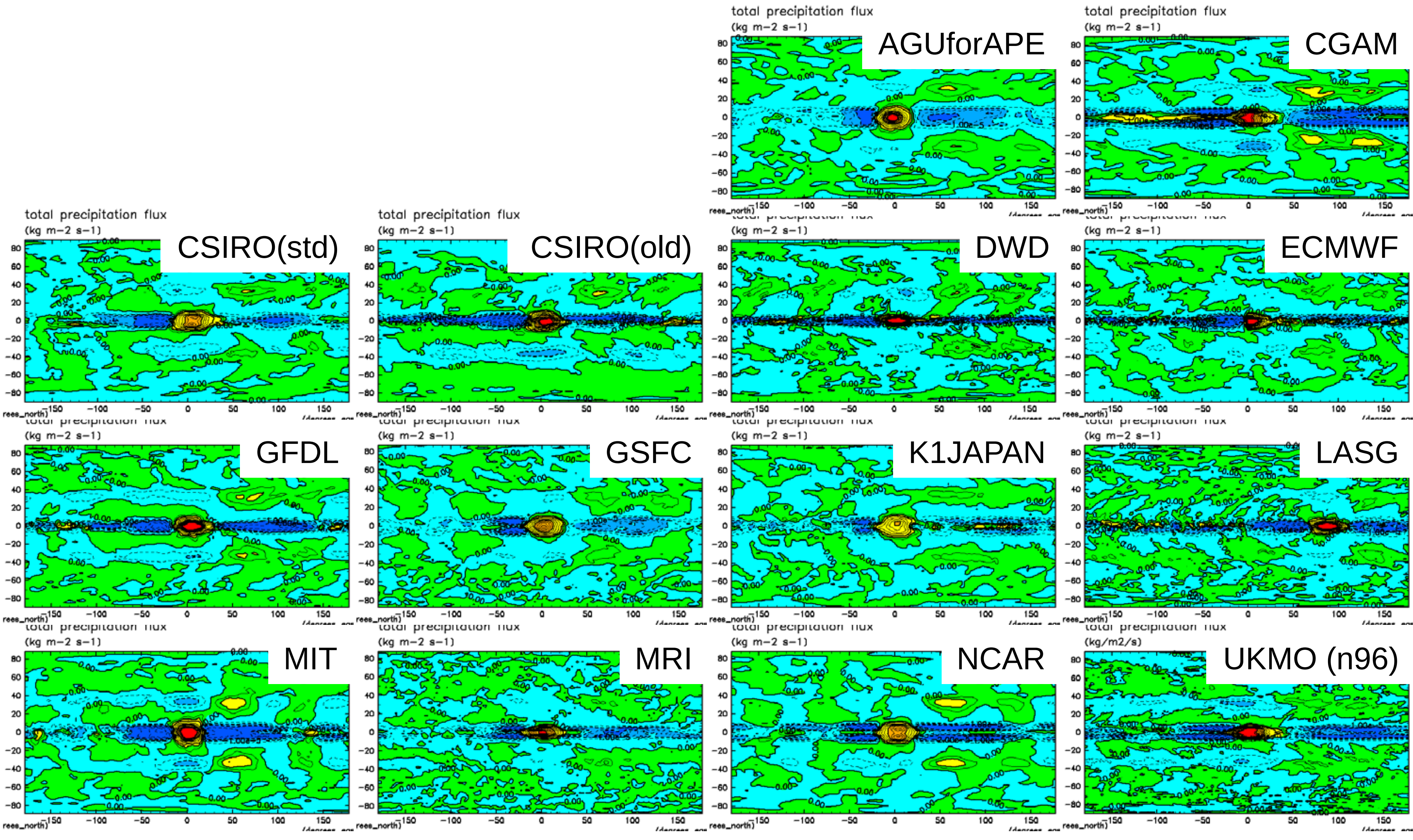
# Response to SSTA on different basic SST distribution (precipitation)




**AGCM5.3 (simple model, T42L16)**

Yamada et al.

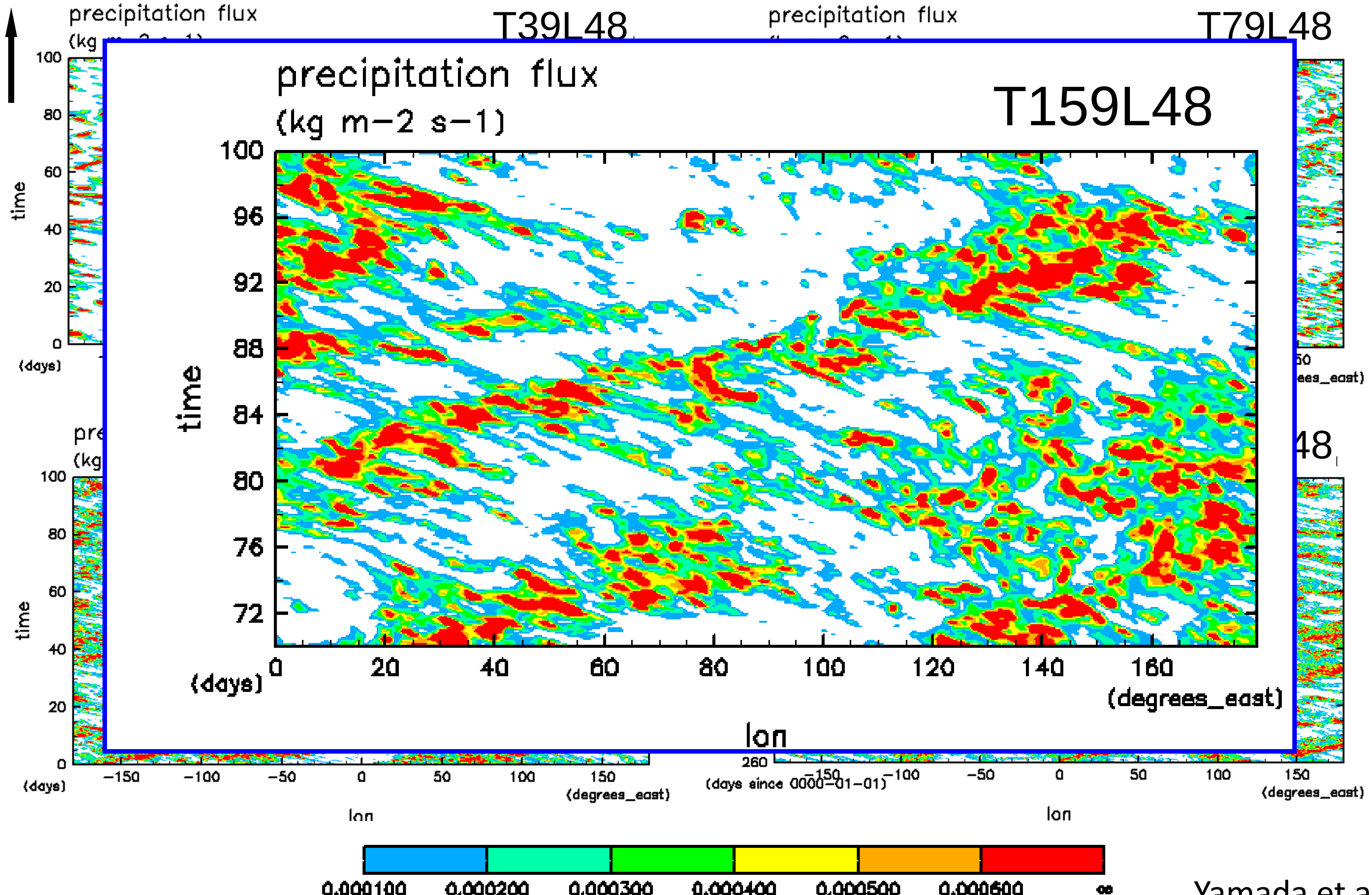
# Precipitation (3keq)



# Resolution Dependence

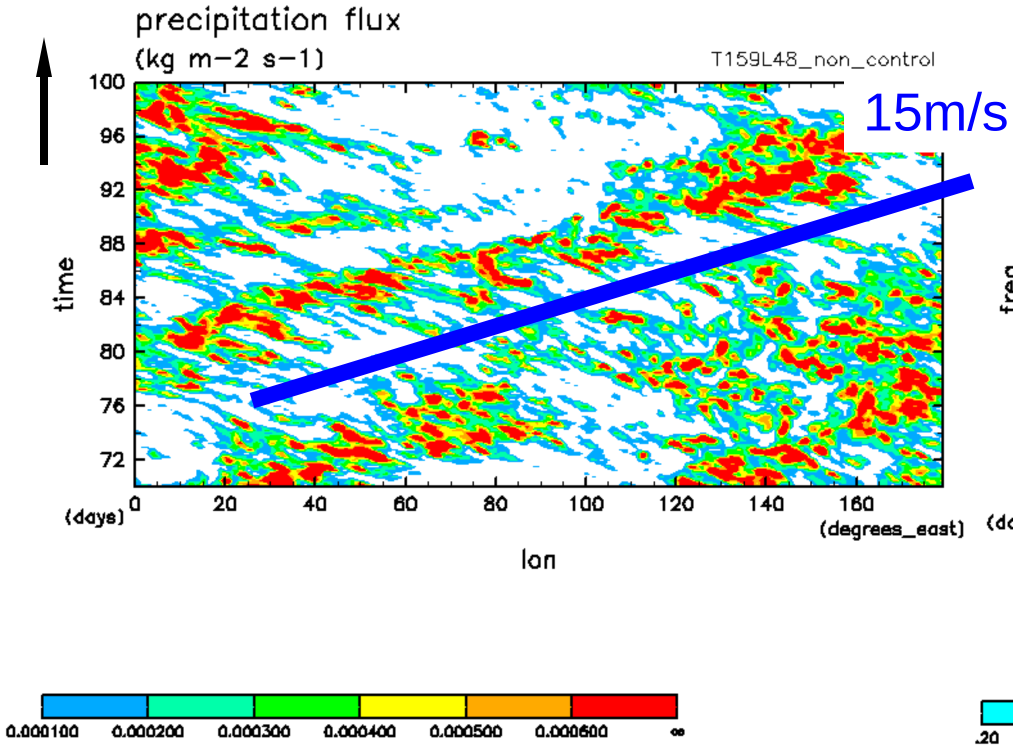
- AFES1.15-ape (CCSR-NIES AGCM 5.4.02 tuned for the Earth Simulator)
  - Cumulus parameterization
    - non: no parameterizaion (only large scale condensation)
  - SST: zonally uniform, symmetric to the equator
    - The control profile of APE
  - Resolution
    - L48
    - T39, T79, T159, T319

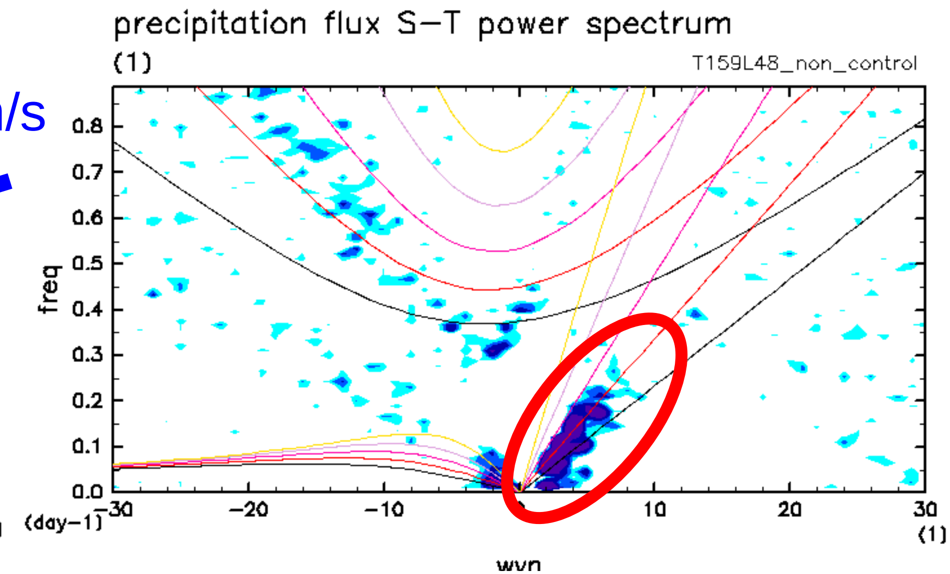
# Dependence on resolution (non)




Yamada et al.

# Dependence on resolution (T159L48_non)



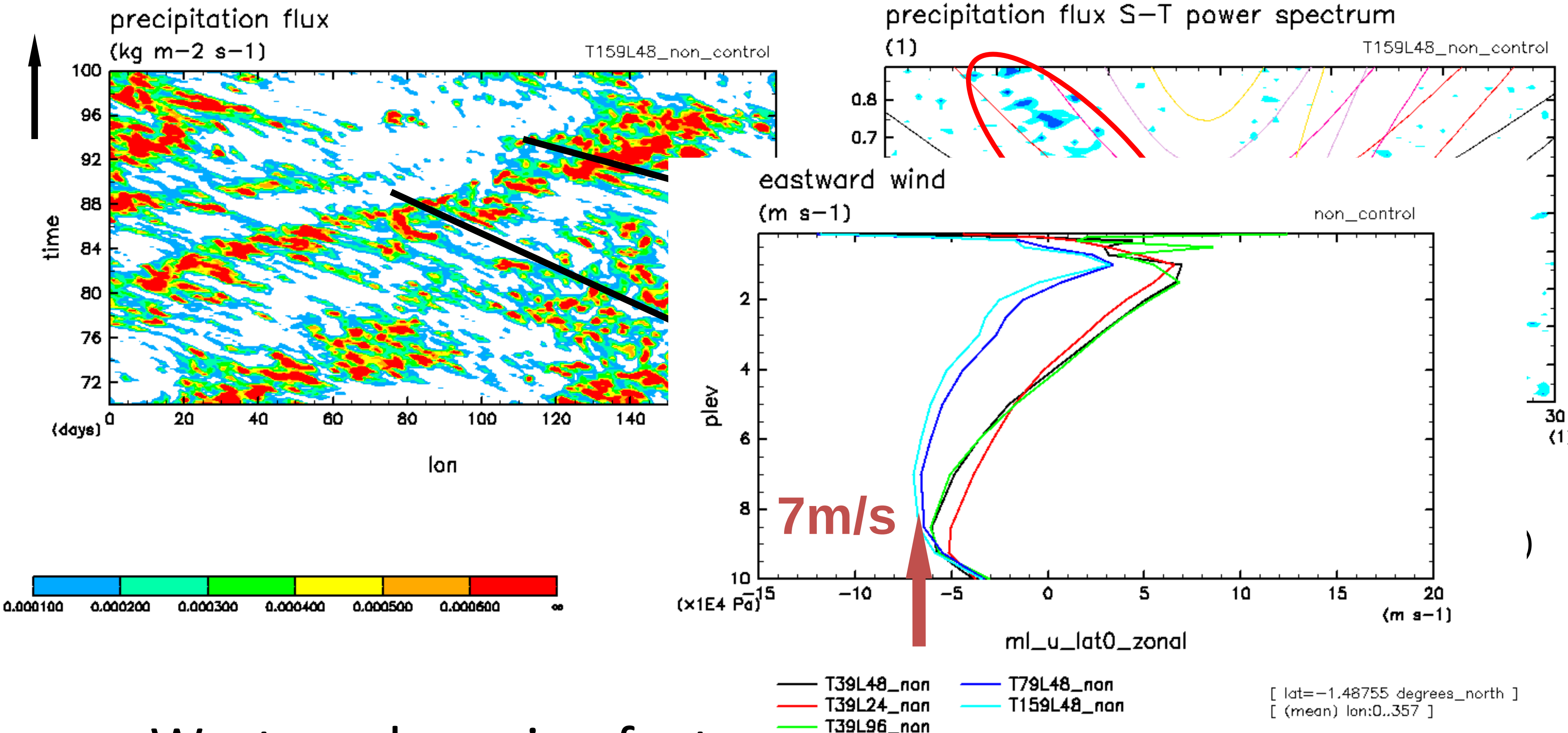




wavenumber-frequency power spectrum calculated as Wheeler and Kiladis (1999)


- Eastward moving features
  - 15m/s

Yamada et al.

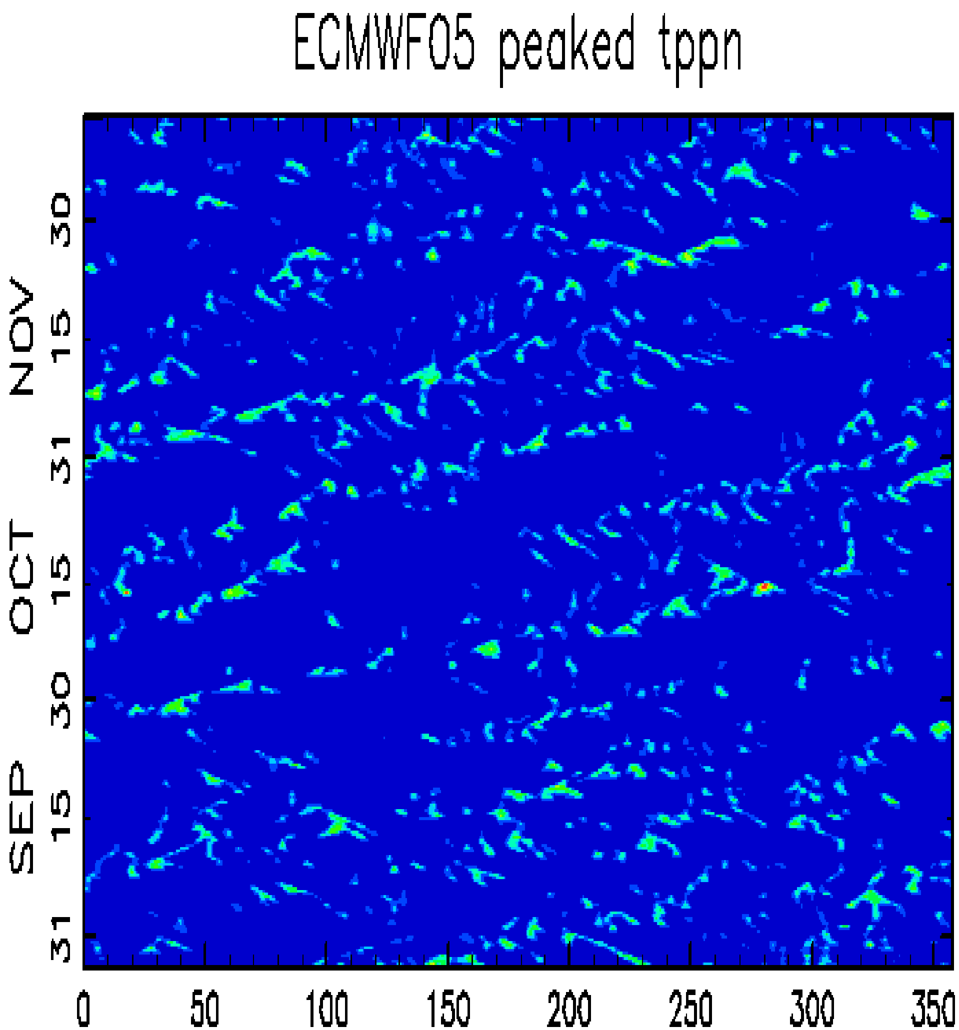
# Dependence on resolution (T159L48_non)

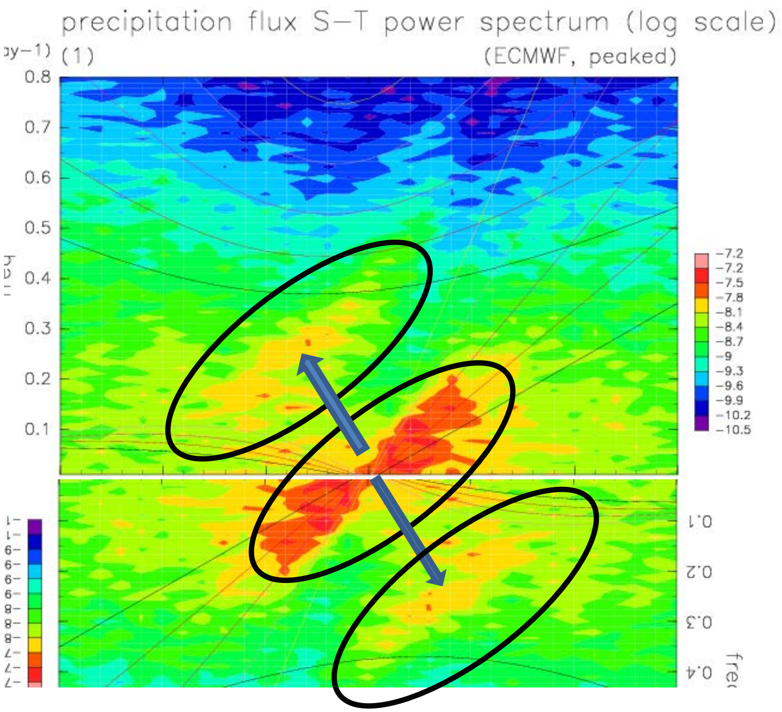



- Westward moving features
  - 15-20m/s
  - 8-10m/s

Yamada et al.

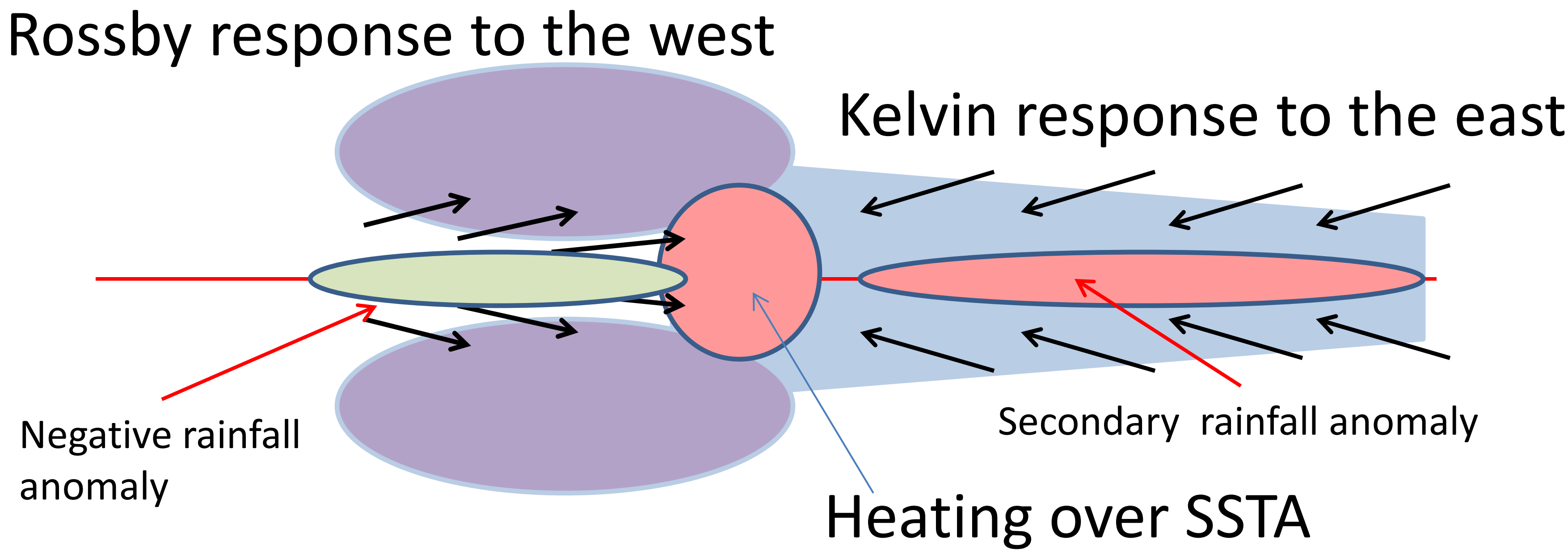
# Characteristic spectrum of IGW from modulation of in Kelvin “envelope”



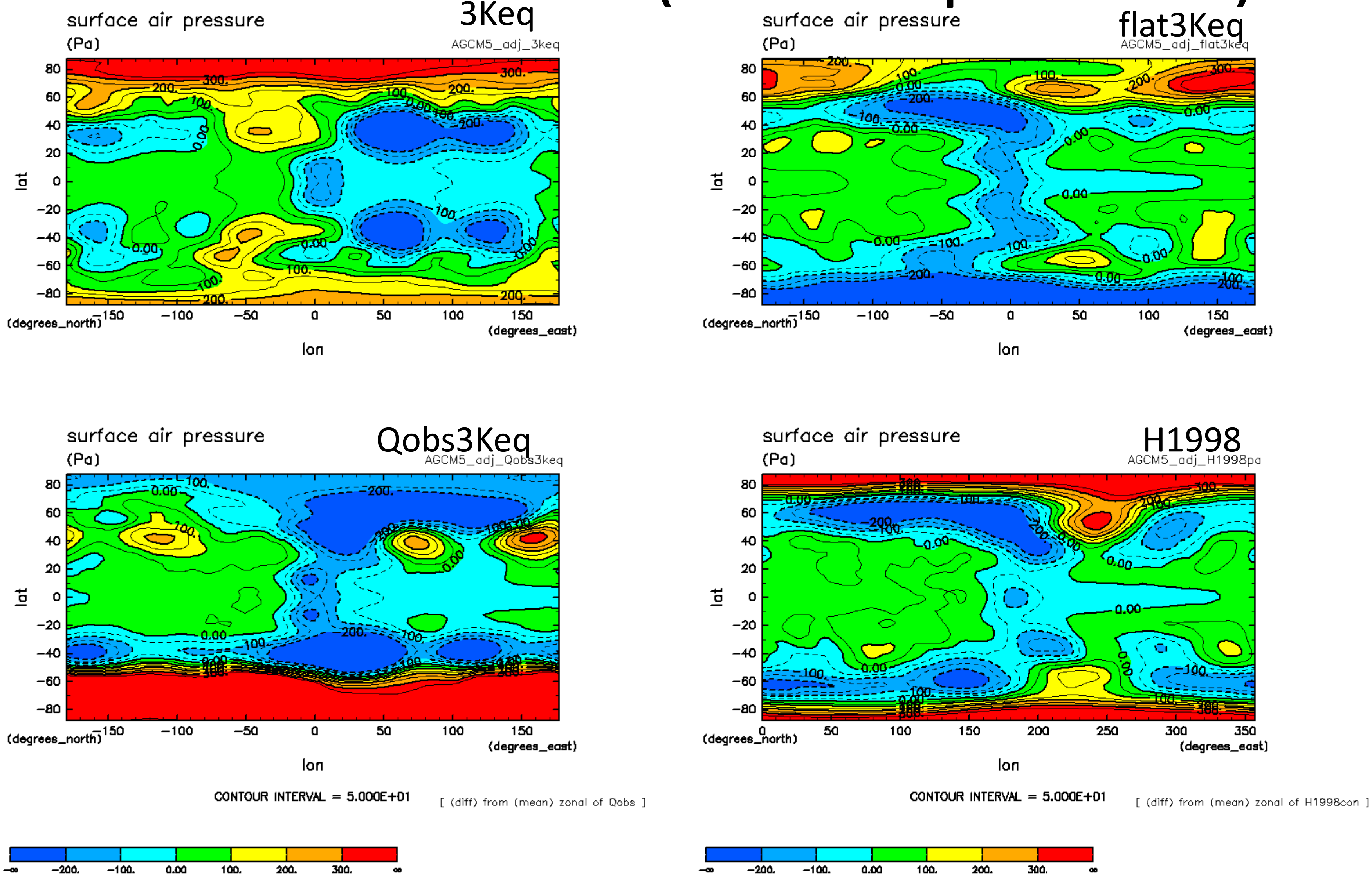

Shift of (k,f) due to a single characteristic inertio gravity wave component?

# Mechanism of the positive rainfall anomaly to the east in Hosaka et al (1998)




We can understand H98 in the framework of "Matsuno-Gill pattern" and Low level Ekman flow

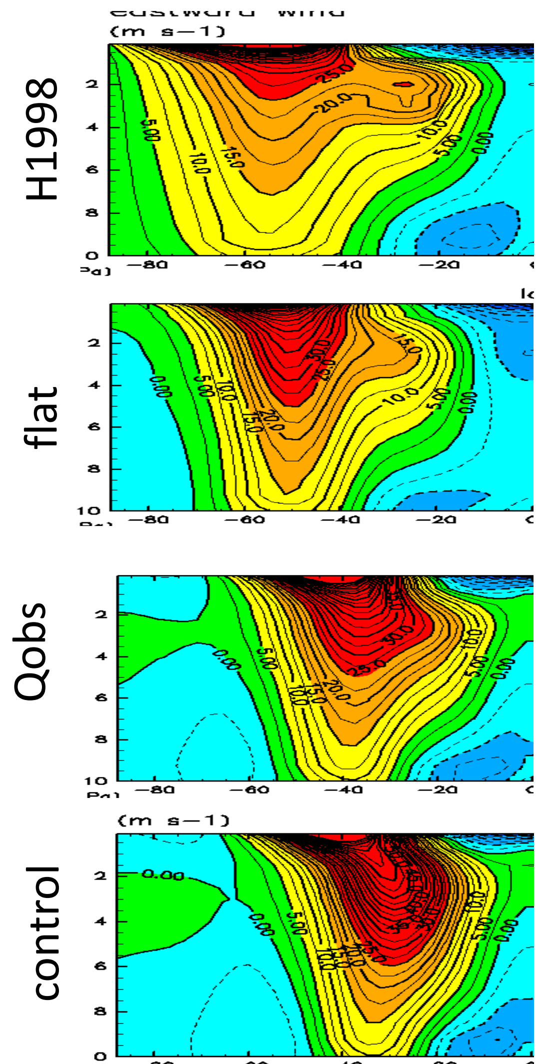
# Response to SSTA on different basic SST distribution (surface pressure)

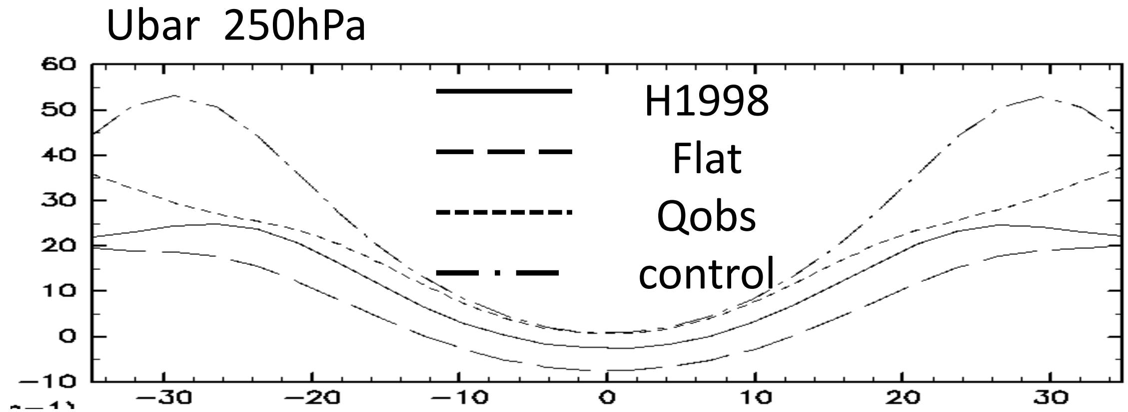


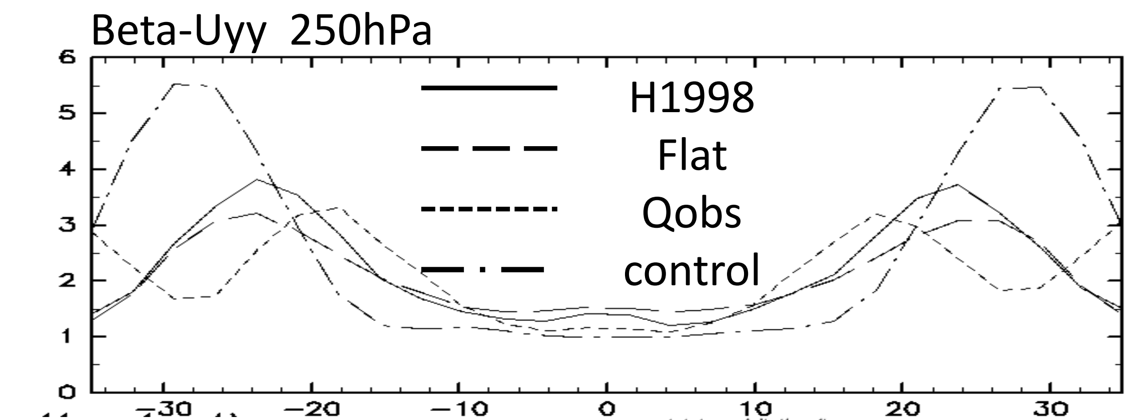

**AGCM5.3 (simple model, T42L16)**

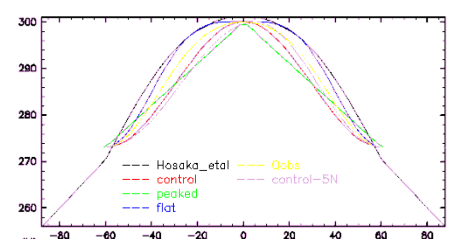
Yamada et al.

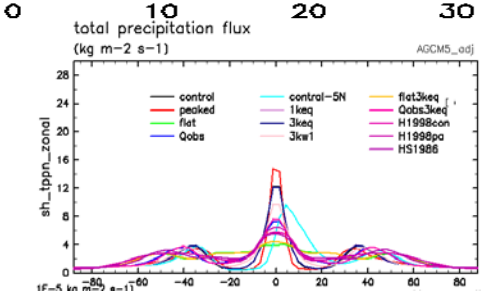
# Importance of “basic states”



# 3KW1 vs “Walker circulation”