EVALUATION OF DYNAMICAL CORES PROPOSED FOR FUTURE VERSIONS OF CAM

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CAM—SE   Spectral Element (aka HOMME)

Icosahedra grid

Mark Taylor

CAM—MPAS   Model for Prediction Across Scales

Cubed sphere grid

Joe Klemp, Bill Skamarock, Art Mirin

CAM—FV3   Finite Volume

Cubed sphere grid

Christiane Jablonowski, Will Sawyer, Art Mirin

CAM—EULAG   EULerian (flux form) or Lagrangian (advective form)

Latitude-longitude grid

Bill Gutowski, Babatunde Abiodun, Piotr Smolarkeiwicz

Climate = statistics of weather

Climate models do not calculate the statistics directly

Statistics calculated from the evolution calculated by the model
after predictability is lost to chaos (IC irrelevant)
and when model has developed its own equilibrium

Climate models conceptually divided into:
  Dynamical core – resolved fluid flow
  Sub-grid scale parameterizations – forcing

What numerical method is “best” for the dynamical core?

Climate models not in a convergent regime
Climate models are in a forced-dissipative equilibrium
Solutions depend on both dynamical core and parameterizations

With a given parameterization suite:

What resolution of one scheme is equivalent to

what resolution of a different scheme?

OTHER CONSIDERATIONS

- CONSERVATION – ENERGY AND TRACERS
- BAROCLINIC EDDY GROWTH
- KINETIC ENERGY SPECTRA
- ERROR GROWTH

EQUIVALENT RESOLUTIONS

CONSERVATION – ENERGY AND TRACERS

Conservation – Energy and Tracers: EXACT OR GOOD ENOUGH?

Chemistry – exact, flux form

Energy – Boville (2000): at least to within 0.1 W/m2

Drift of deep ocean in coupled system

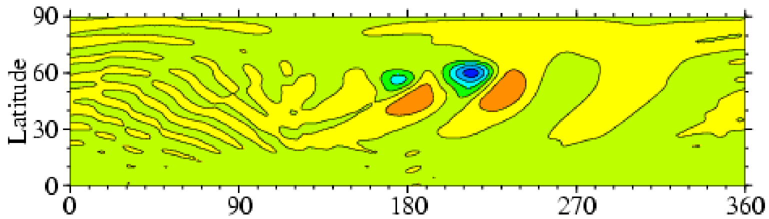
large enough to imply a non-equilibrium solution

BAROCLINIC EDDY GROWTH

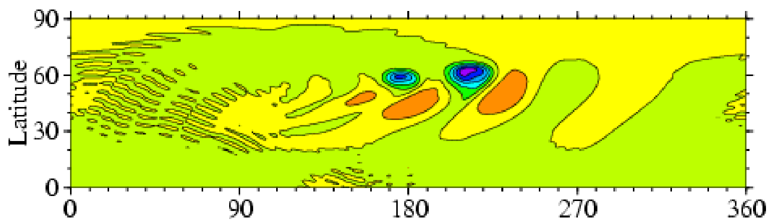
SURFACE PRESSURE DAY 9

EULERIAN SPECTRAL

T42

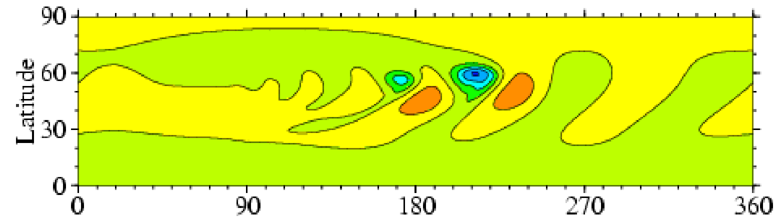


T85

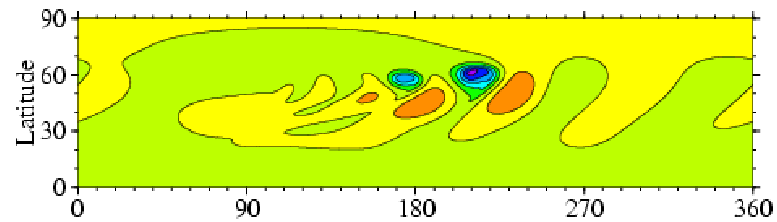


FINITE VOLUME

2.0 x 2.5



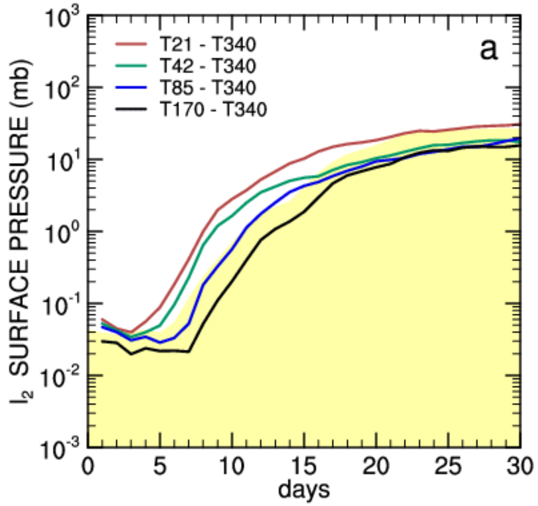
1.0 x 1.25



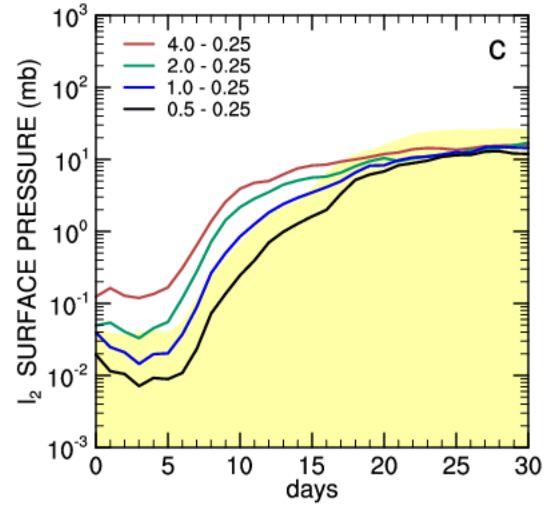
Jablonowski and Williamson 2006

SURFACE PRESSURE RMS ERROR

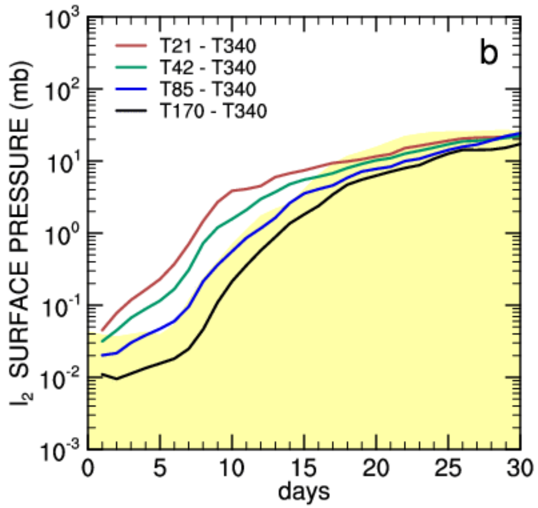
EULERIAN SPECTRAL



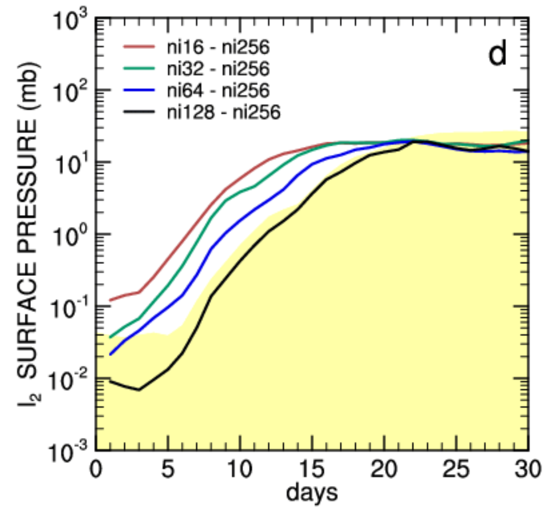
FINITE VOLUME



SEMI-LAGRANGIAN



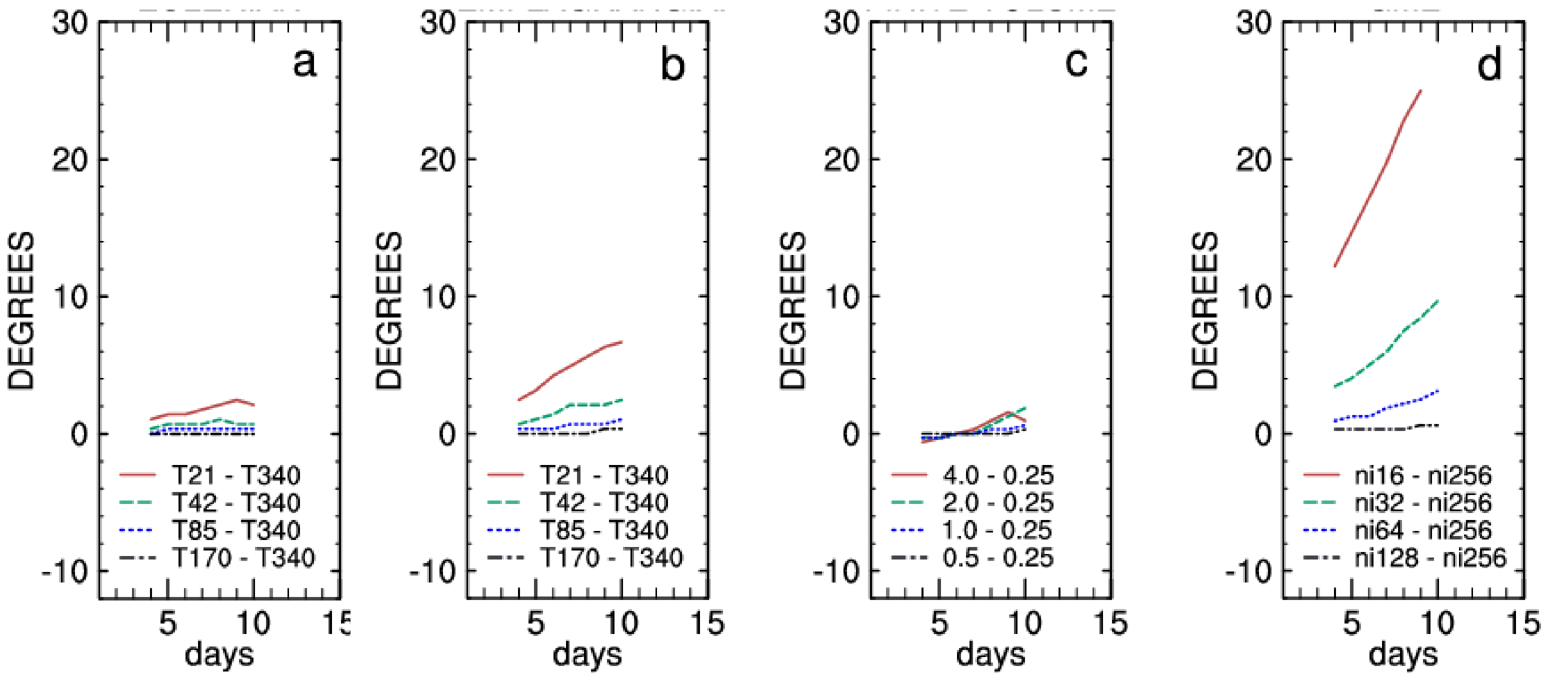
GME



Jablonowski and Williamson 2006

SURFACE PRESSURE PHASE ERROR

EULERIAN SPECTRAL | SEMI—LAGRANGIAN | FINITE VOLUME | GME

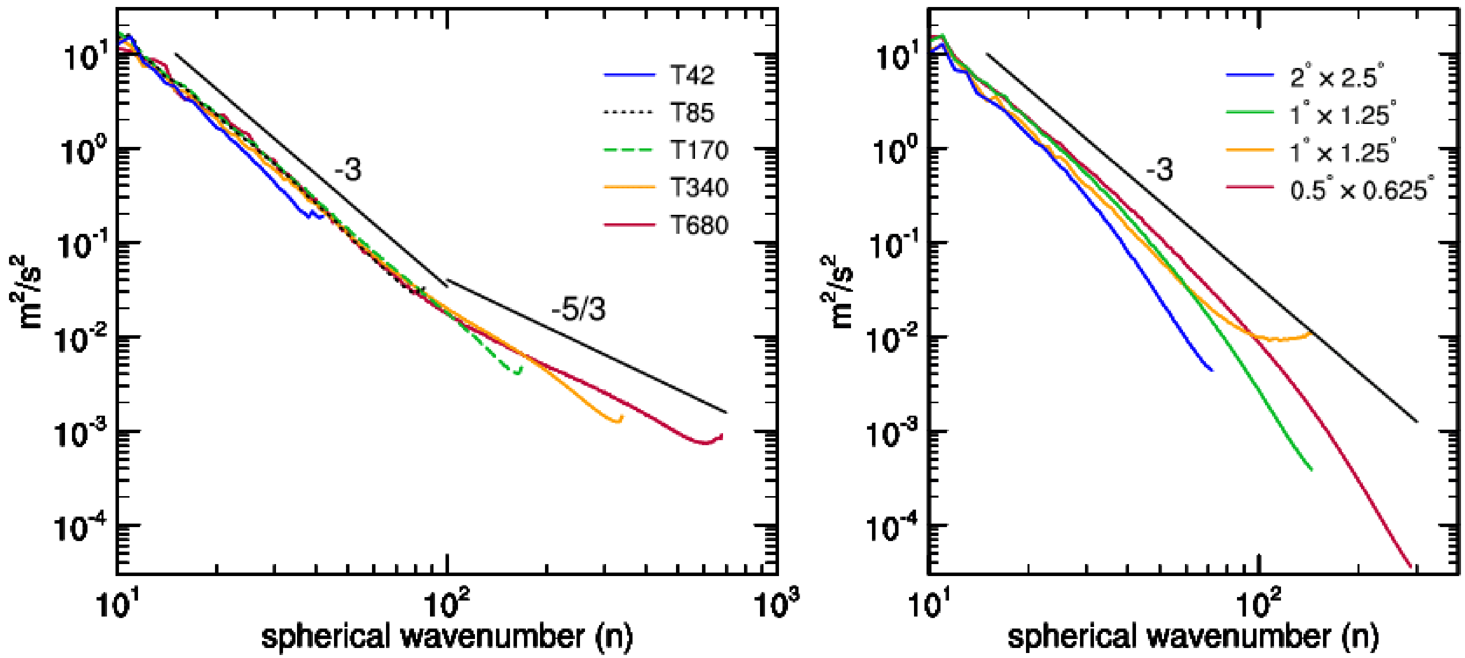


Jablonowski and Williamson 2006

KINETIC ENERGY SPECTRA

EULERIAN SPECTRAL

FINITE VOLUME

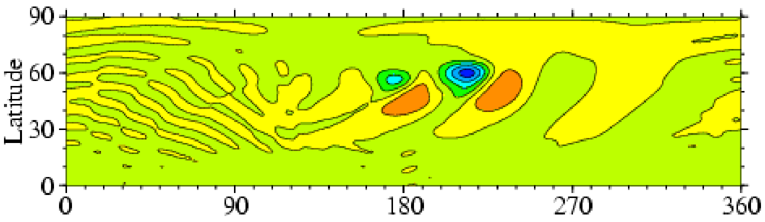


Jablonowski and Williamson 2011

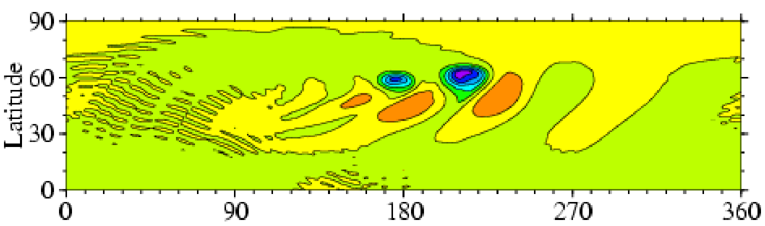
SURFACE PRESSURE   DAY 9

EULERIAN SPECTRAL

T42

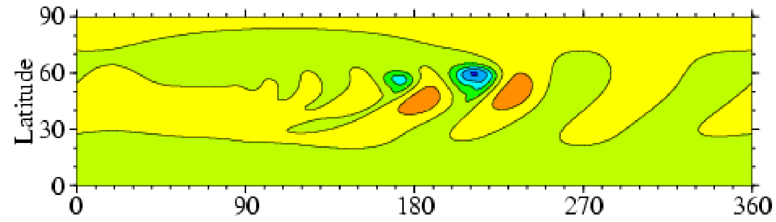


T85

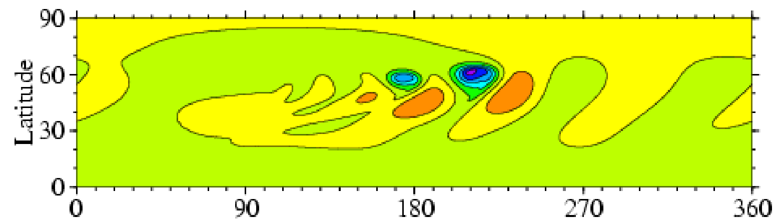


FINITE VOLUME

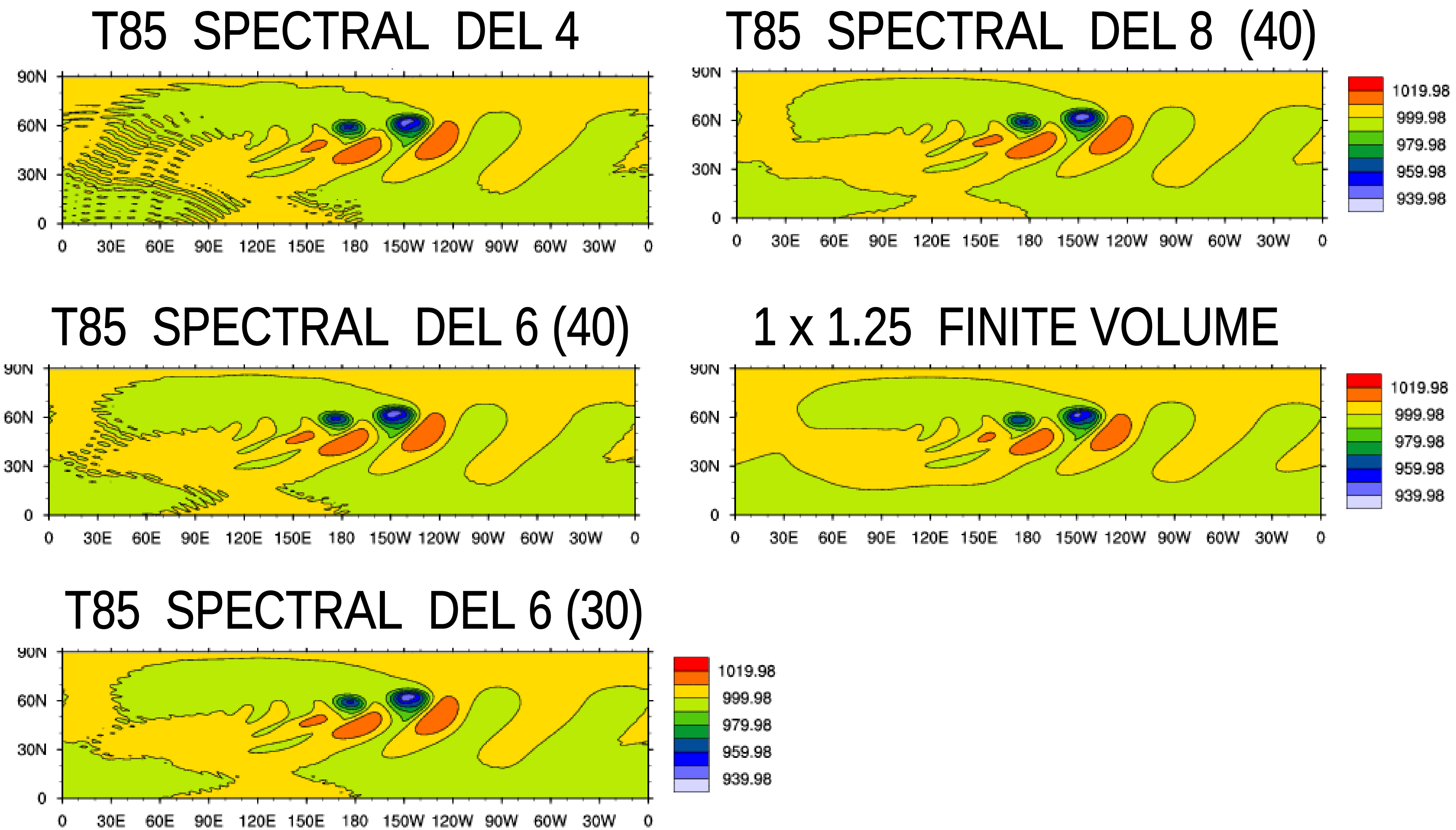
2.0 x 2.5



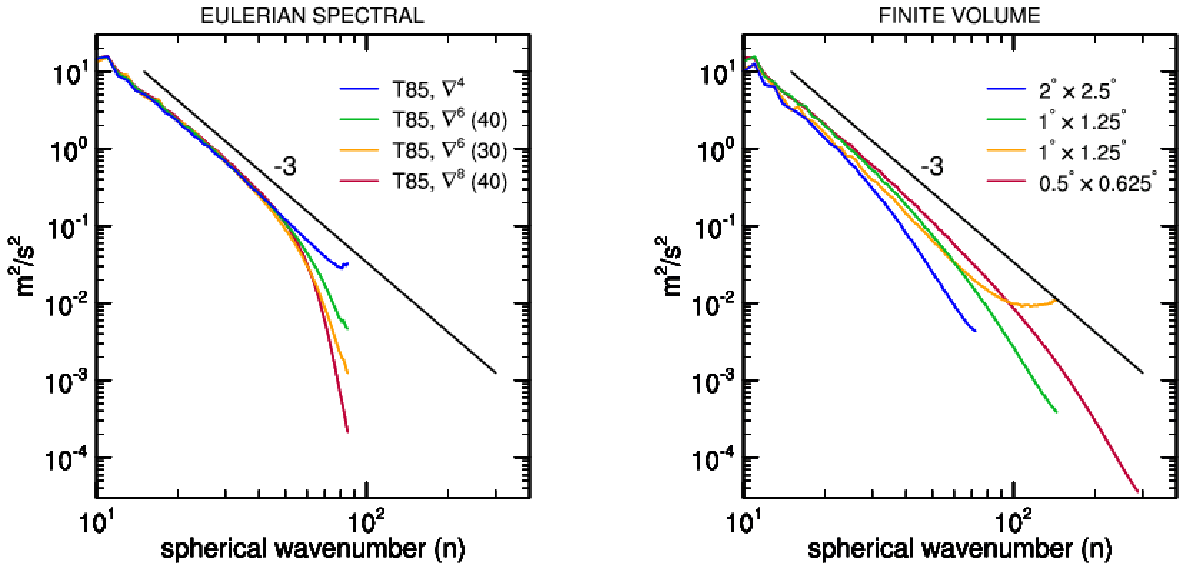
1.0 x 1.25



Jablonowski and Williamson 2006

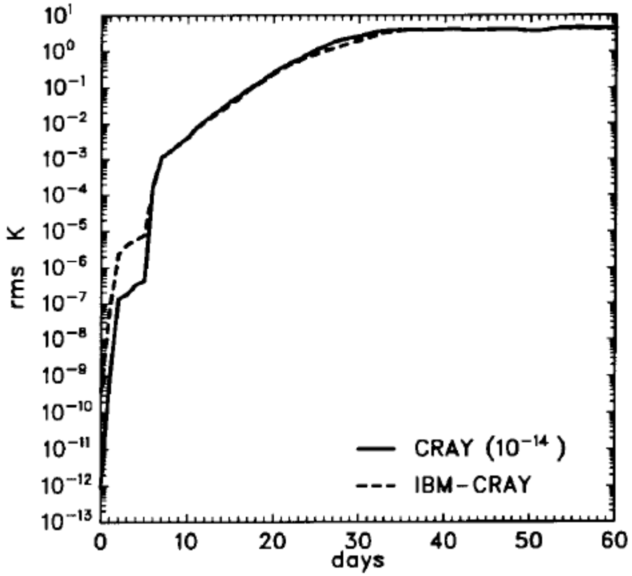


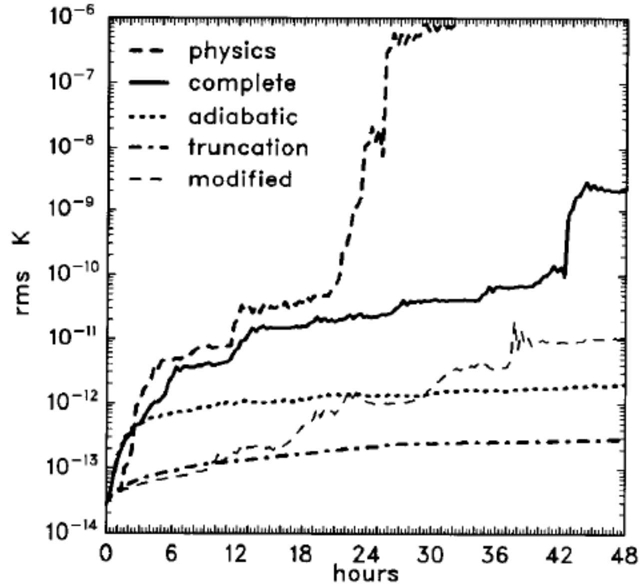
Jablonowski and Williamson 2011



Jablonowski and Williamson 2011

ERROR GROWTH





Rosinski and Williamson 1997

EQUIVALENT RESOLUTIONS

AQUA-PLANET SIMULATIONS

Atmospheric model with complete parameterization suite

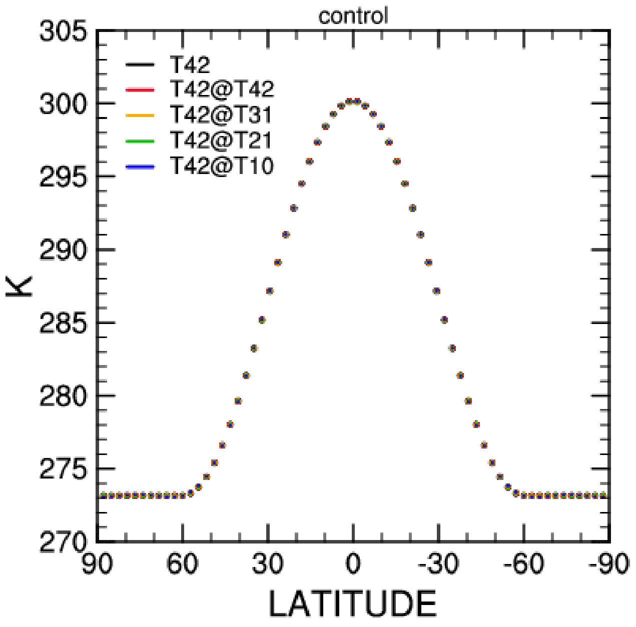
Idealized surface

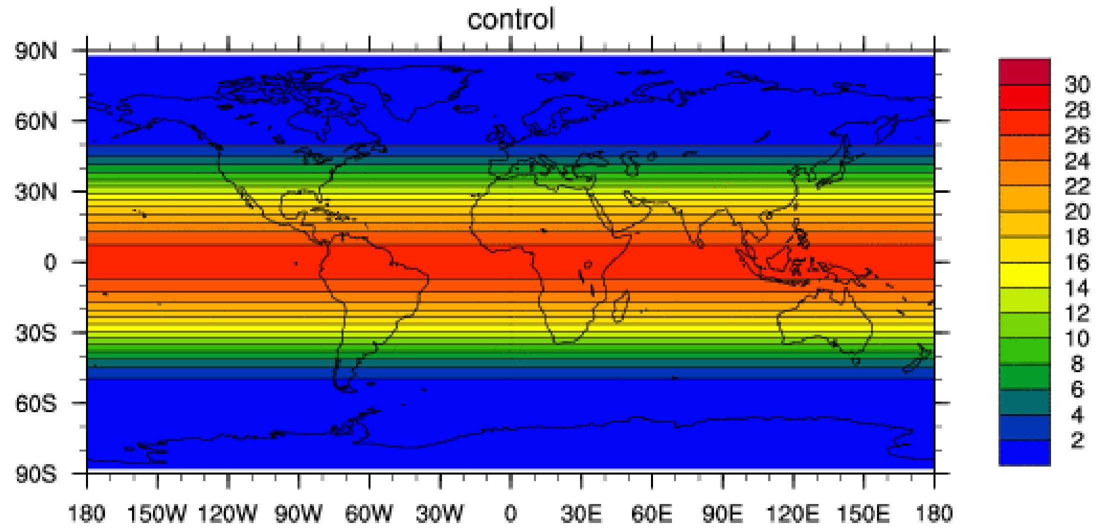
- no land (or mountains), no sea ice
- specified global sea surface temperatures everywhere
  - longitudinally symmetric
  - latitudinally well resolved

Free motions, no forced component

Neale and Hoskins 2000

SEA SURFACE TEMPERATURE





Neale and Hoskins 2000

Community Atmosphere Model (CAM3)

Eulerian Spectral Transform
Finite Volume

CAM 3.1 Parameterization Package
T85 setting of adjustable constants
5 minute time step

14 month simulations, analysis over last 12 months

Williamson 2008

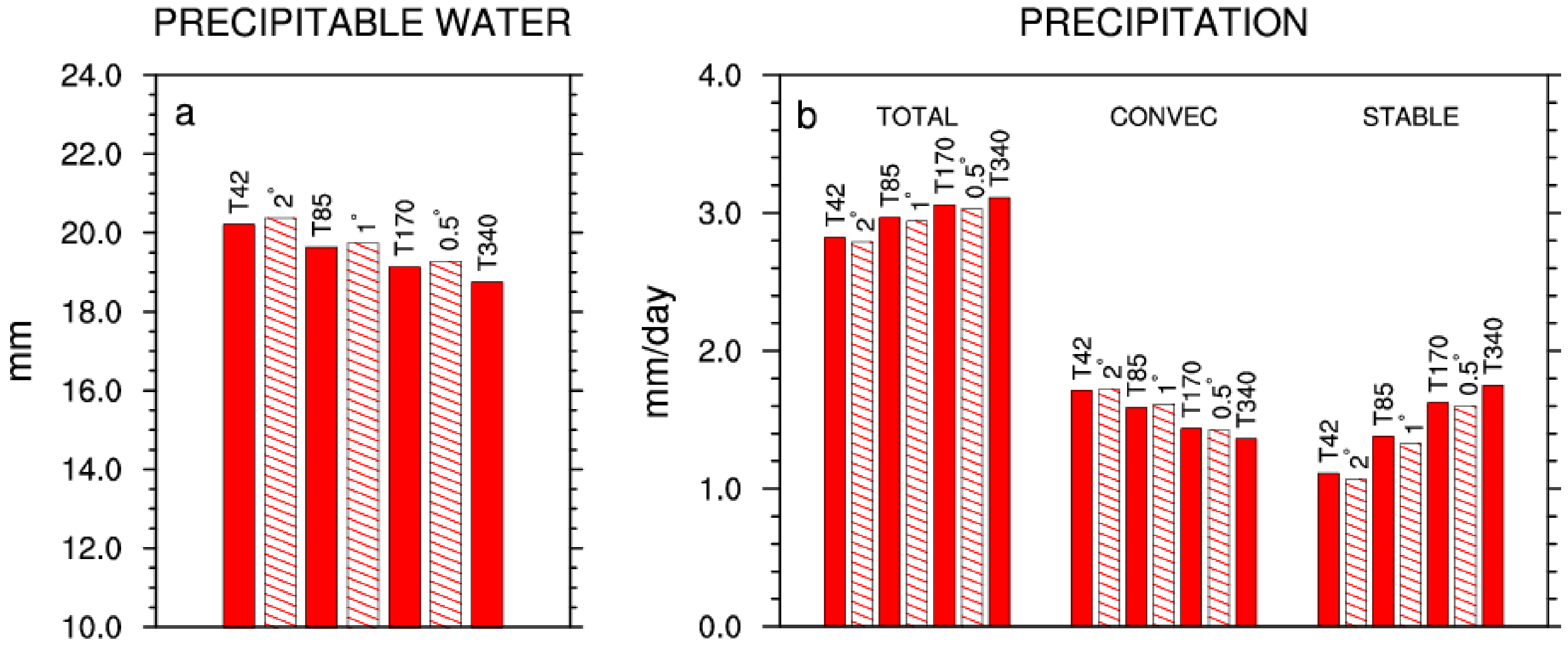
2 degree Finite Volume is equivalent to
T42 Spectral Transform with 2.8 degree transform grid

1 degree Finite Volume is equivalent to
T85 Spectral Transform with 1.4 degree transform grid

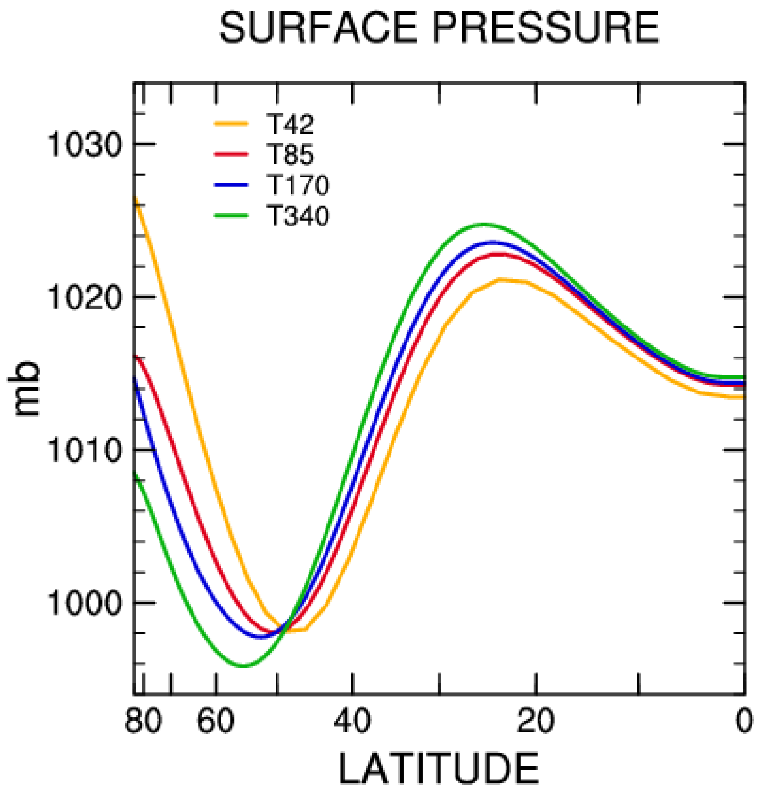
EQUIVALENT CONSIDERATIONS

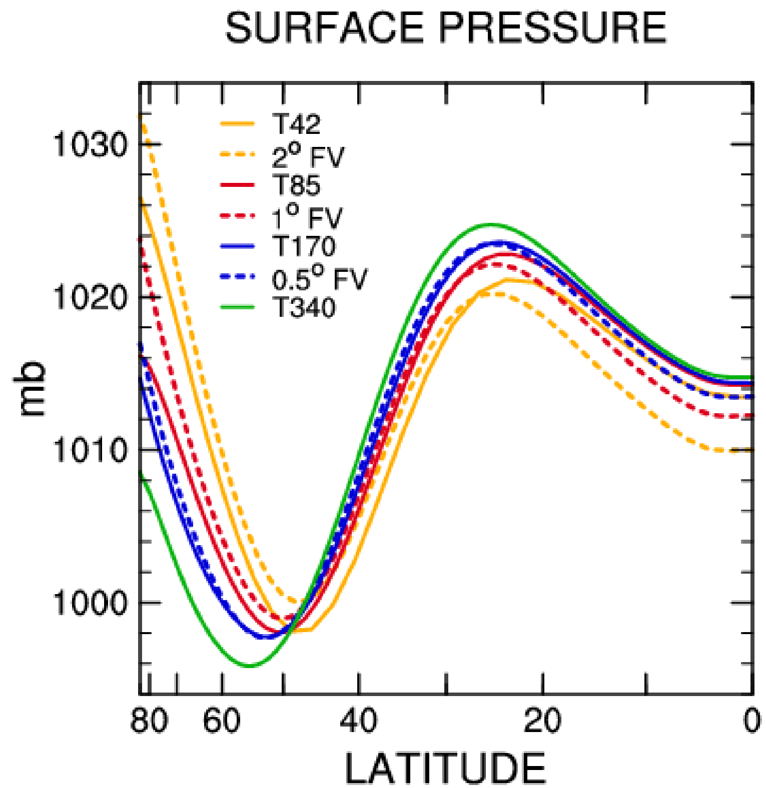
- GLOBAL AVERAGE, TIME AVERAGE
- LONGITUDINAL AVERAGE, TIME AVERAGE
- TEMPORAL EDDY COVARIANCES
- TROPICAL WAVE ACTIVITY
- FREQUENCY DISTRIBUTION OF TROPICAL PRECIPITATION

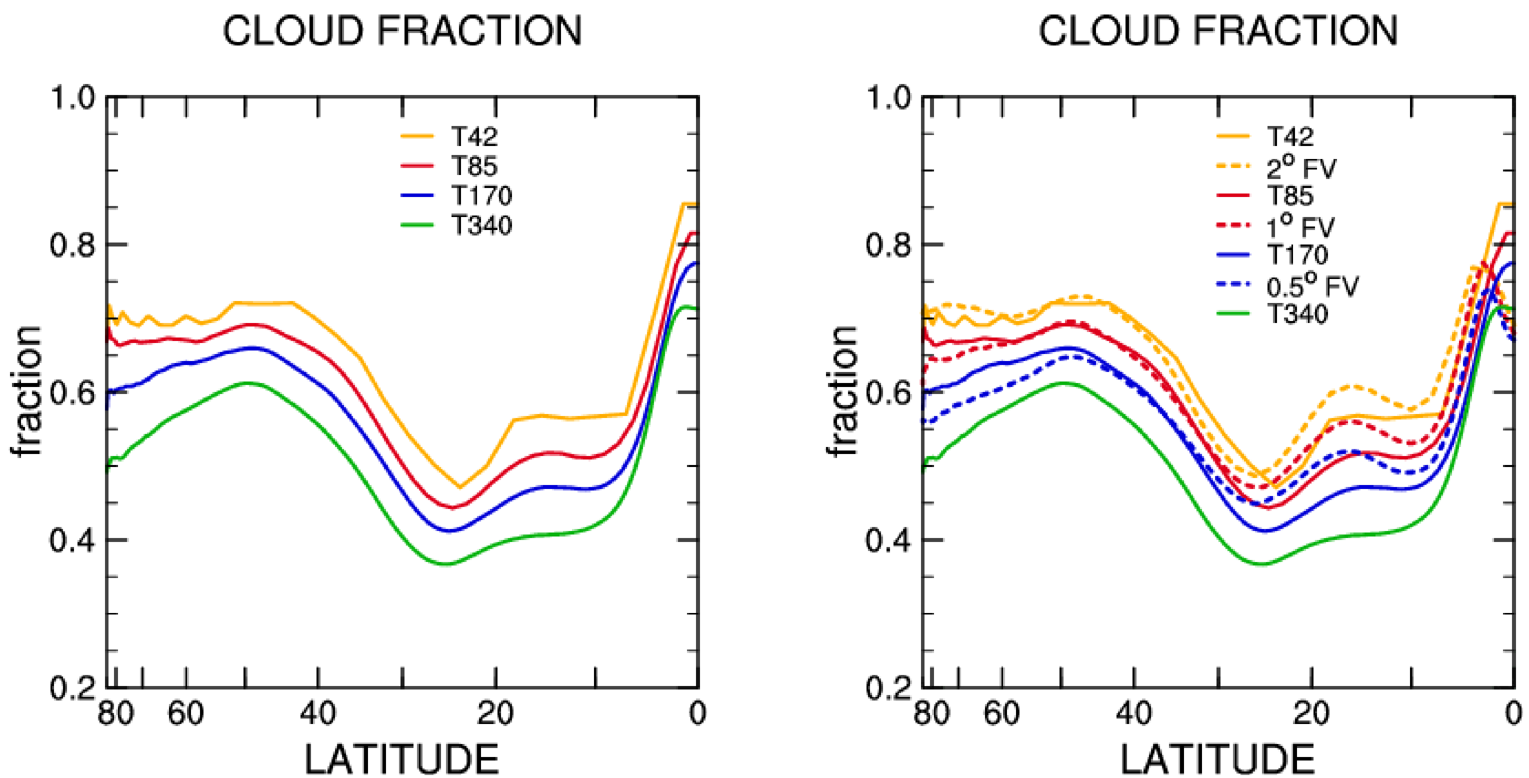
(A brief diversion on double versus single ICTZ)



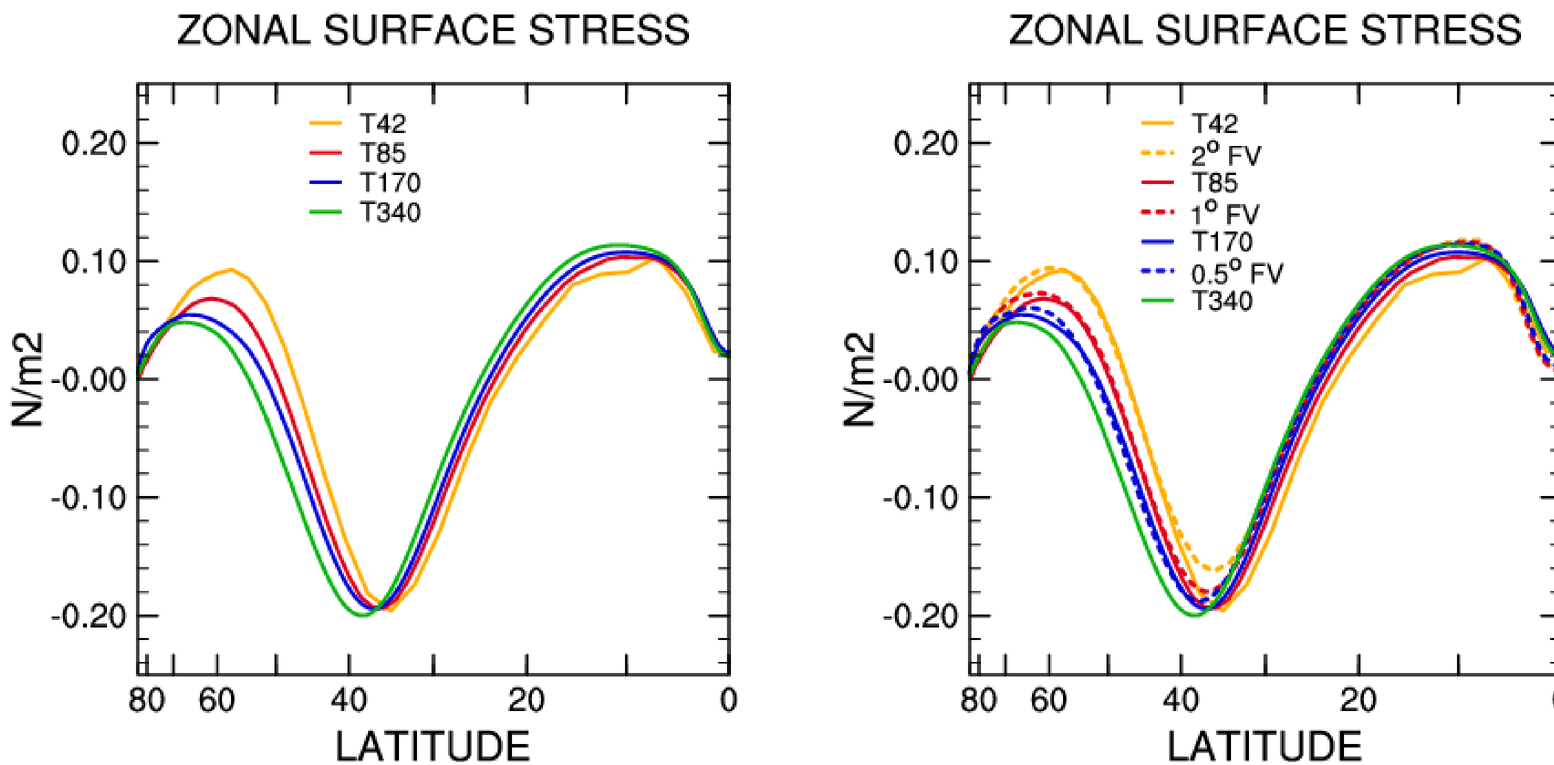
PRECIPITABLE WATER
a
mm
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
T42
2°
T85
1°
T170
0.5°
T340
PRECIPITATION
b
mm/day
4.0
3.0
2.0
1.0
0.0
TOTAL
CONVEC
STABLE


SURFACE PRESSURE
T42
T85
T170
T340
1030
1020
1010
1000
mb
80
60
40
20
0
LATITUDE

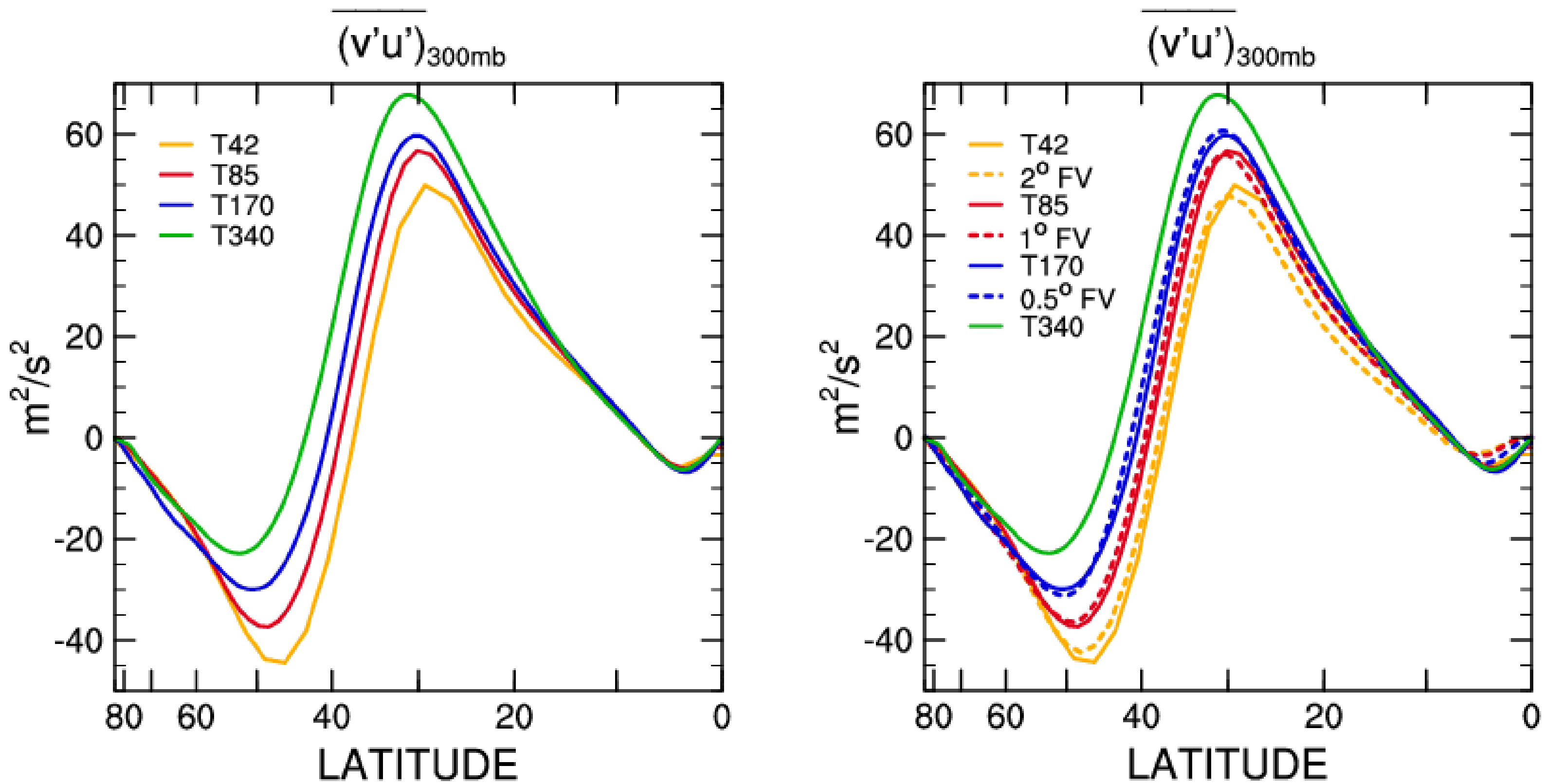

SURFACE PRESSURE
T42
2° FV
T85
1° FV
T170
0.5° FV
T340
1030
1020
1010
1000
mb
80
60
40
20
0
LATITUDE



CLOUD FRACTION
1.0
0.8
0.6
0.4
0.2
fraction
80
60
40
20
0
LATITUDE
T42
T85
T170
T340
CLOUD FRACTION
1.0
0.8
0.6
0.4
0.2
fraction
80
60
40
20
0
LATITUDE
T42
2° FV
T85
1° FV
T170
0.5° FV
T340



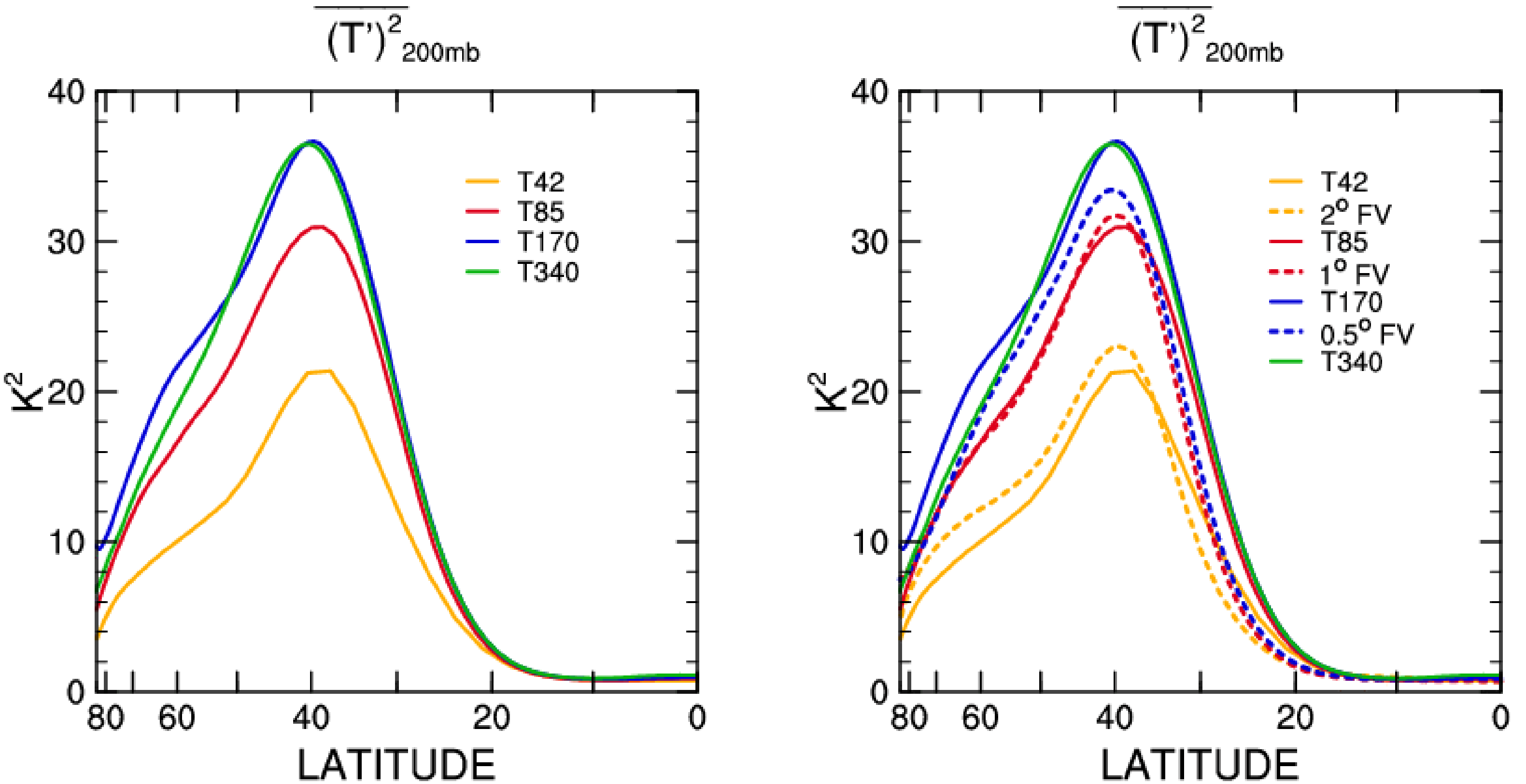
ZONAL SURFACE STRESS
T42
T85
T170
T340
0.20
0.10
-0.00
-0.10
-0.20
N/m2
80
60
40
20
0
LATITUDE
ZONAL SURFACE STRESS
T42
2° FV
T85
1° FV
T170
0.5° FV
T340
0.20
0.10
-0.00
-0.10
-0.20
N/m2
80
60
40
20
0
LATITUDE



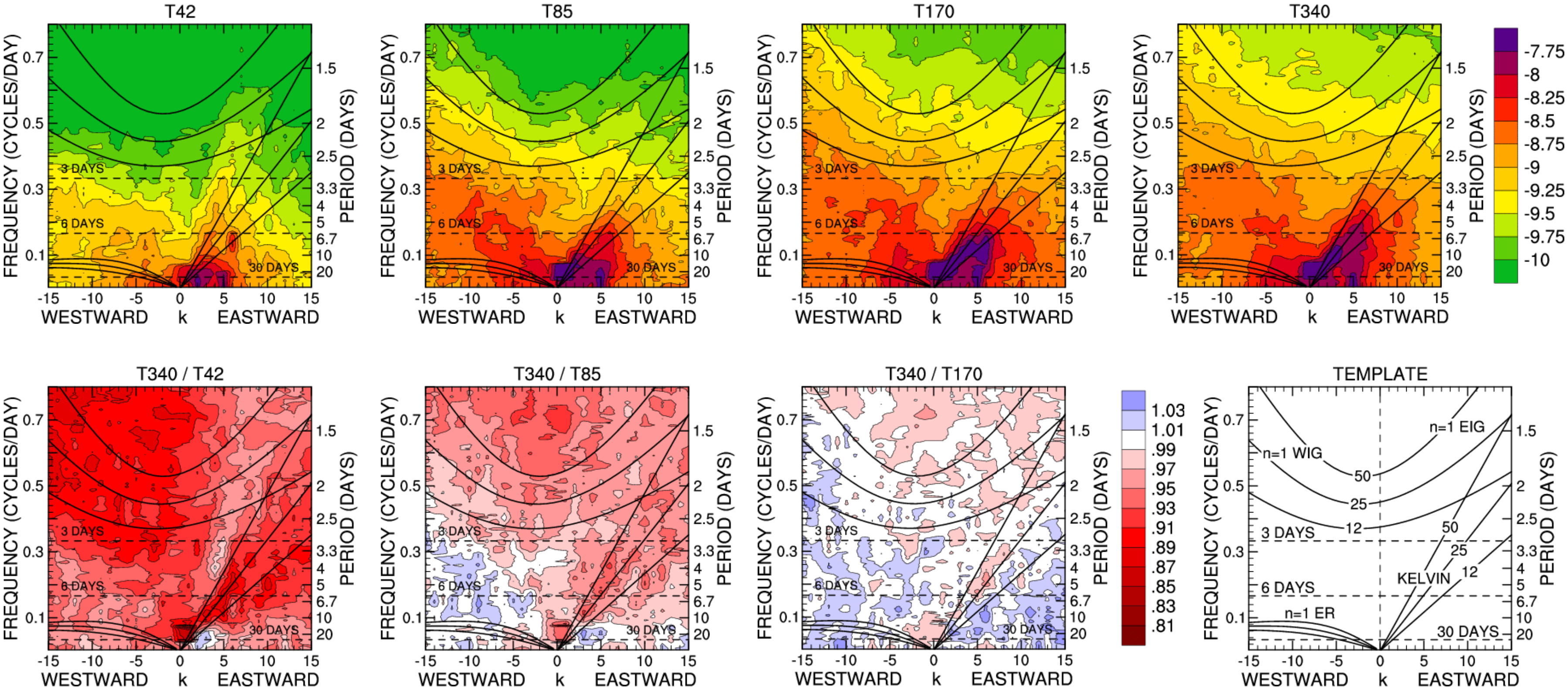
$$\overline{u} = \text{time average}$$

$$u = \overline{u} + u'$$

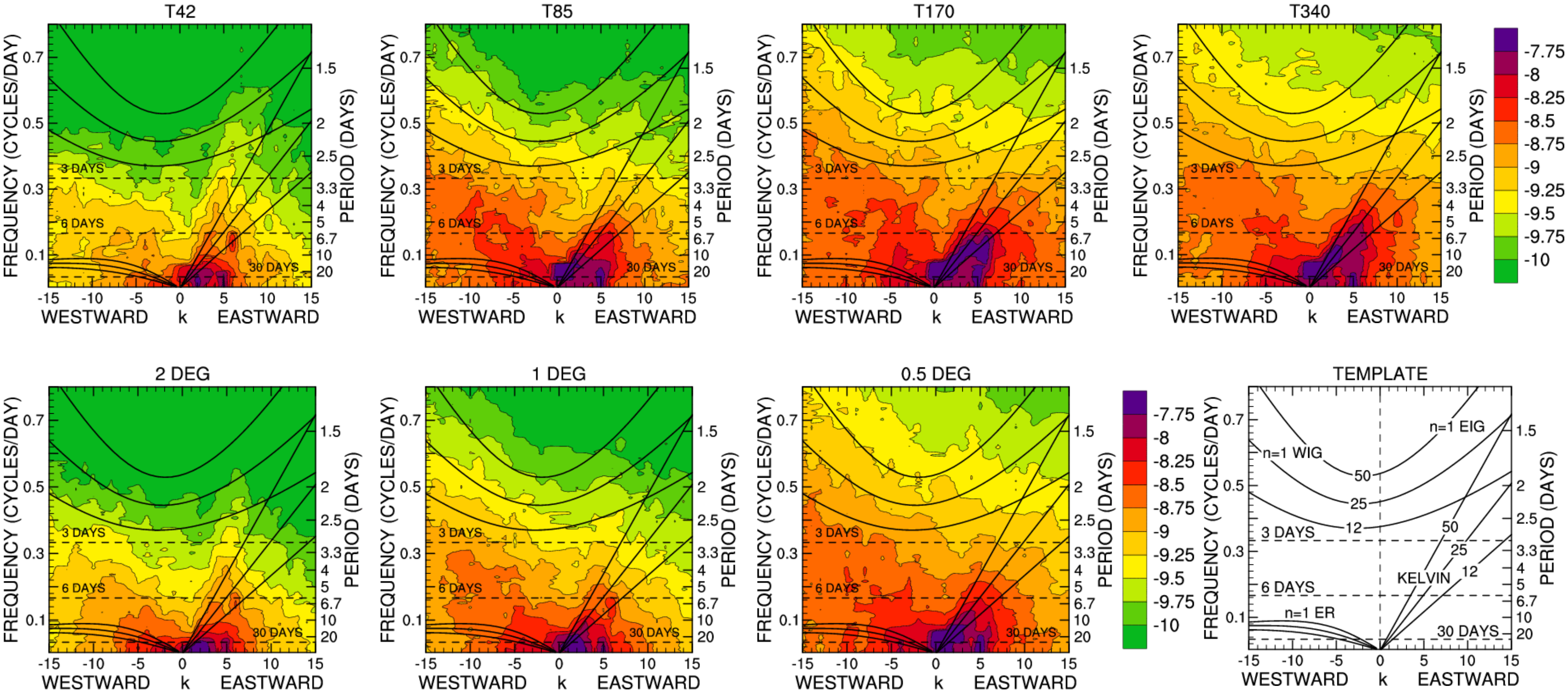
$$\overline{uv} = \overline{u}\;\overline{v} + \overline{u'v'}$$

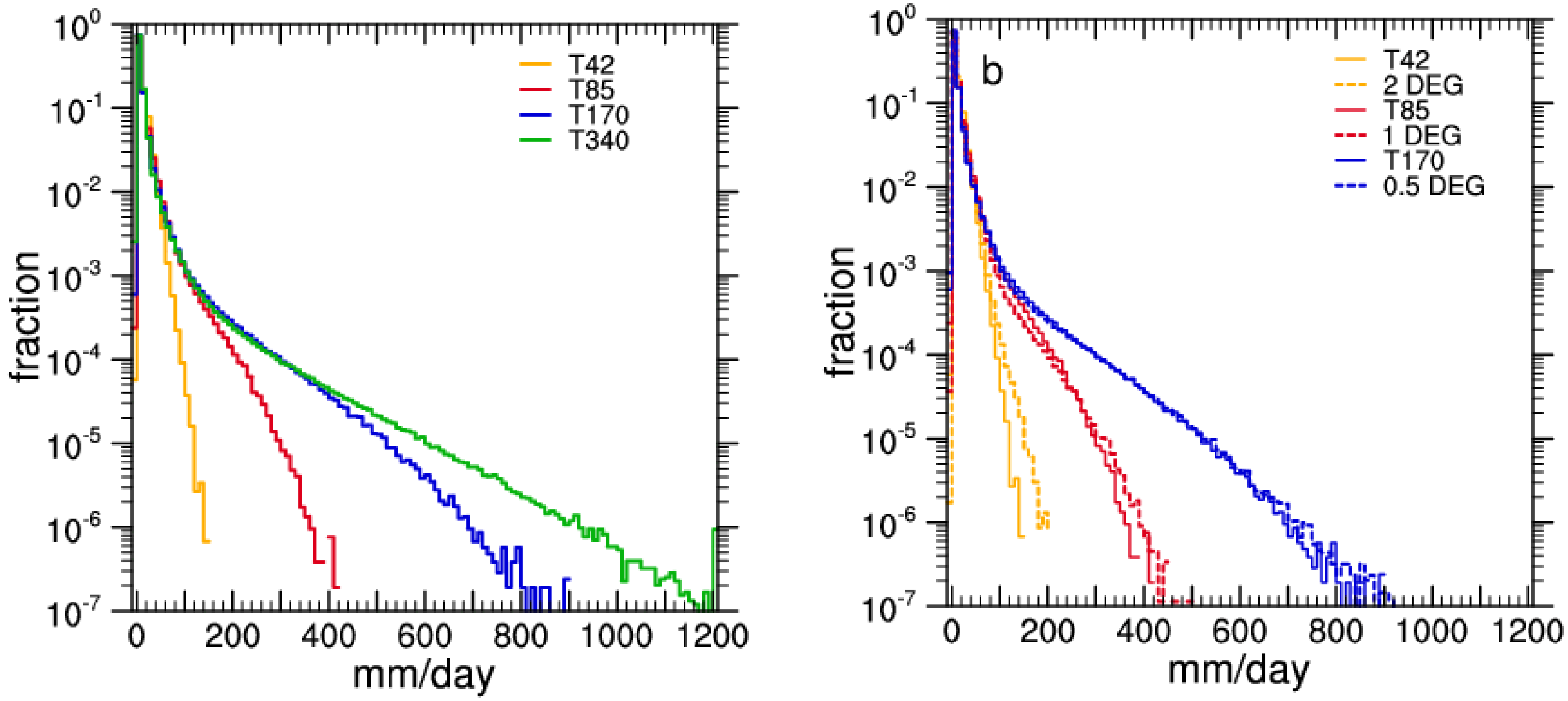


$\overline{(T')^2}_{200mb}$
K²
LATITUDE
T42
T85
T170
T340
$\overline{(T')^2}_{200mb}$
K²
LATITUDE
T42
2° FV
T85
1° FV
T170
0.5° FV
T340



T42
T85
T170
T340
T340 / T42
T340 / T85
T340 / T170
TEMPLATE
FREQUENCY (CYCLES/DAY)
PERIOD (DAYS)
WESTWARD
k
EASTWARD
3 DAYS
6 DAYS
30 DAYS
-7.75
-8
-8.25
-8.5
-8.75
-9
-9.25
-9.5
-9.75
-10
1.03
1.01
.99
.97
.95
.93
.91
.89
.87
.85
.83
.81
n=1 WIG
n=1 EIG
n=1 ER
KELVIN
50
25
12

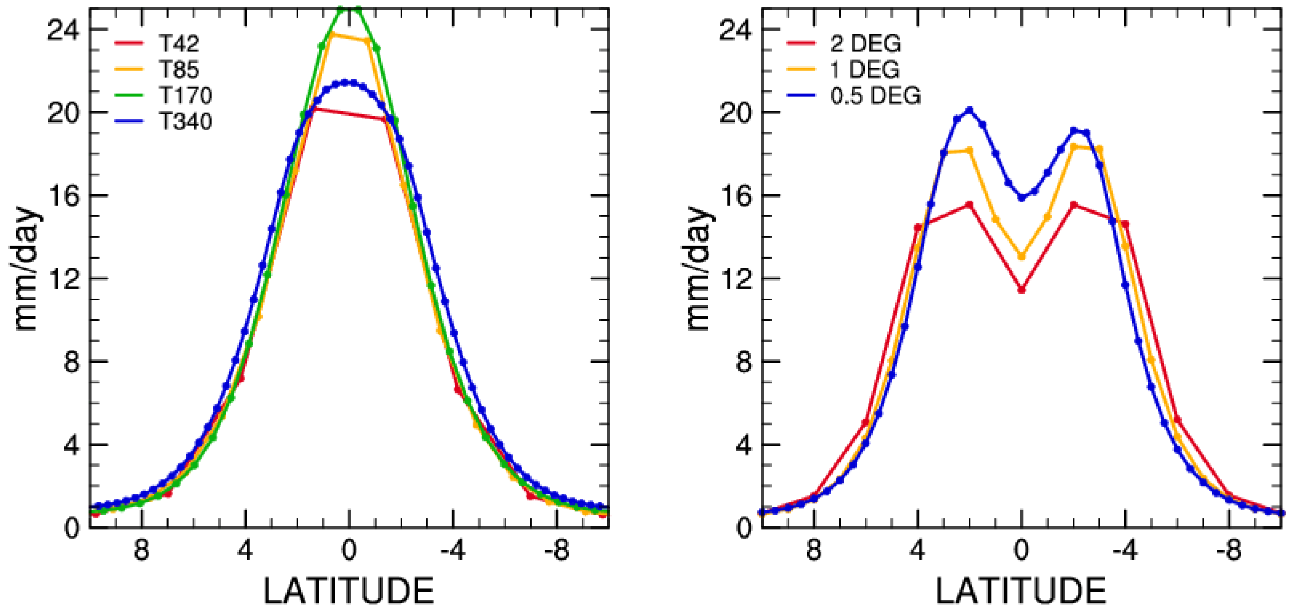

T42
T85
T170
T340
2 DEG
1 DEG
0.5 DEG
TEMPLATE
FREQUENCY (CYCLES/DAY)
PERIOD (DAYS)
WESTWARD
k
EASTWARD
3 DAYS
6 DAYS
30 DAYS
-7.75
-8
-8.25
-8.5
-8.75
-9
-9.25
-9.5
-9.75
-10
n=1 WIG
n=1 EIG
n=1 ER
KELVIN
50
25
12

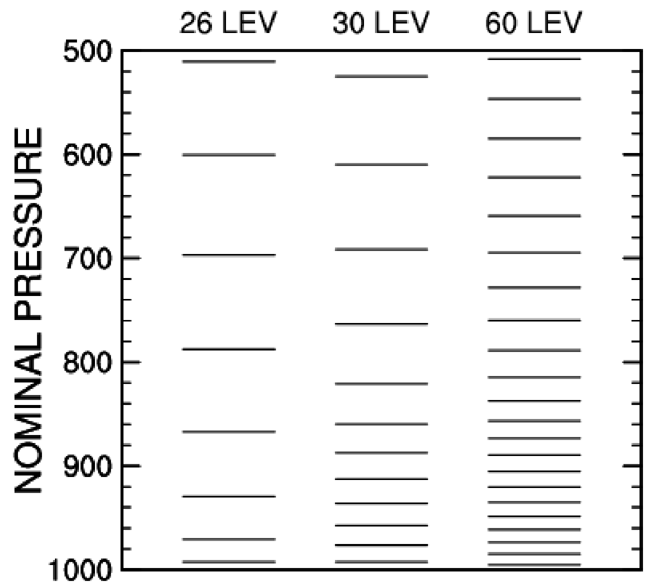


T42
T85
T170
T340
fraction
mm/day
b
T42
2 DEG
T85
1 DEG
T170
0.5 DEG
fraction
mm/day

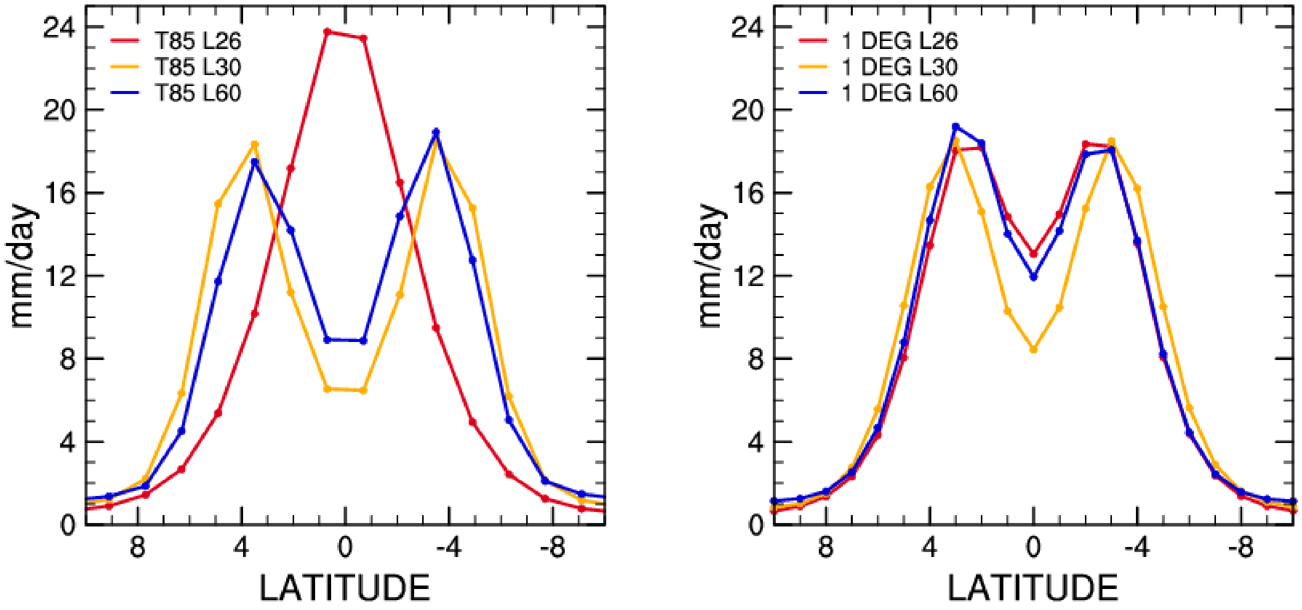
DOUBLE VERSUS SINGLE ICTZ
or
VERTICAL RESOLUTION

PRECIPITATION




26 LEV
30 LEV
60 LEV
NOMINAL PRESSURE
500
600
700
800
900
1000

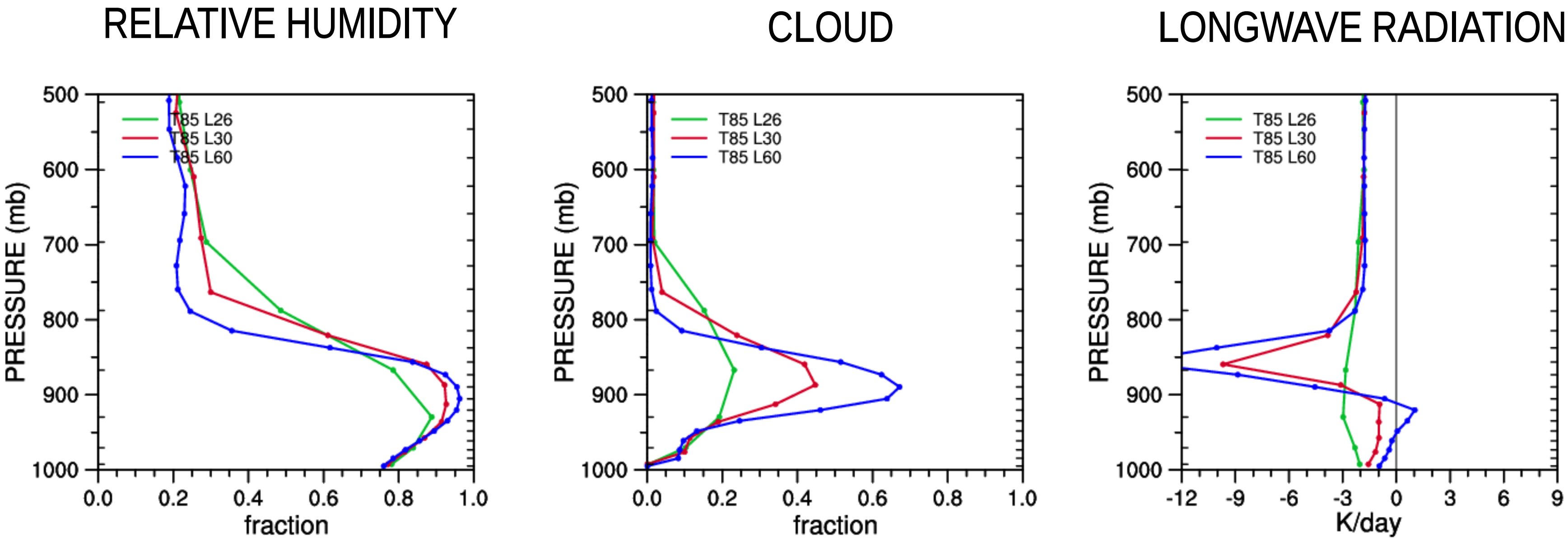
PRECIPITATION



Williamson 2011

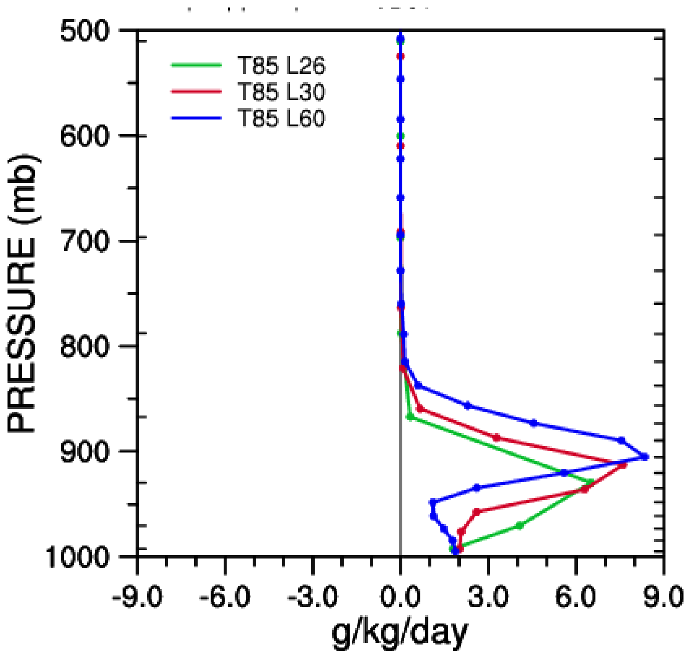
Examine averages over the subsidence region poleward of the upward branch of the Hadley cell

Meridional average |7.5| to |17.5|
Zonal average

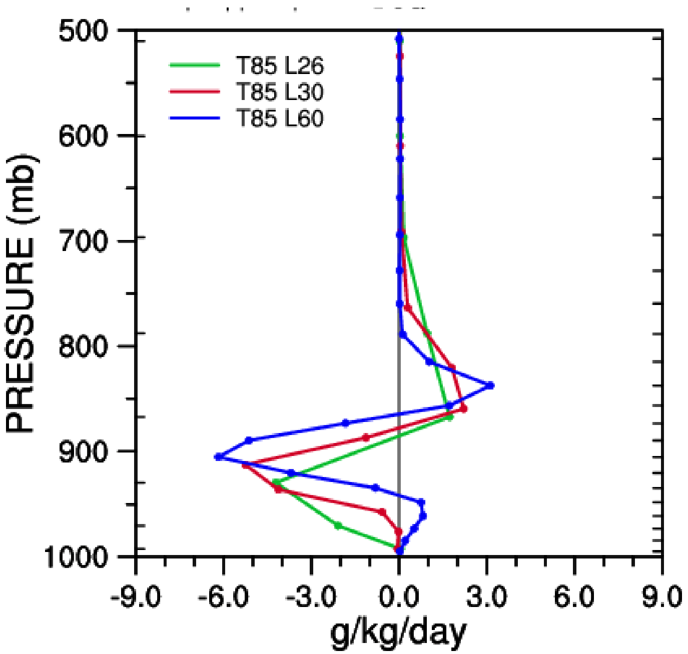


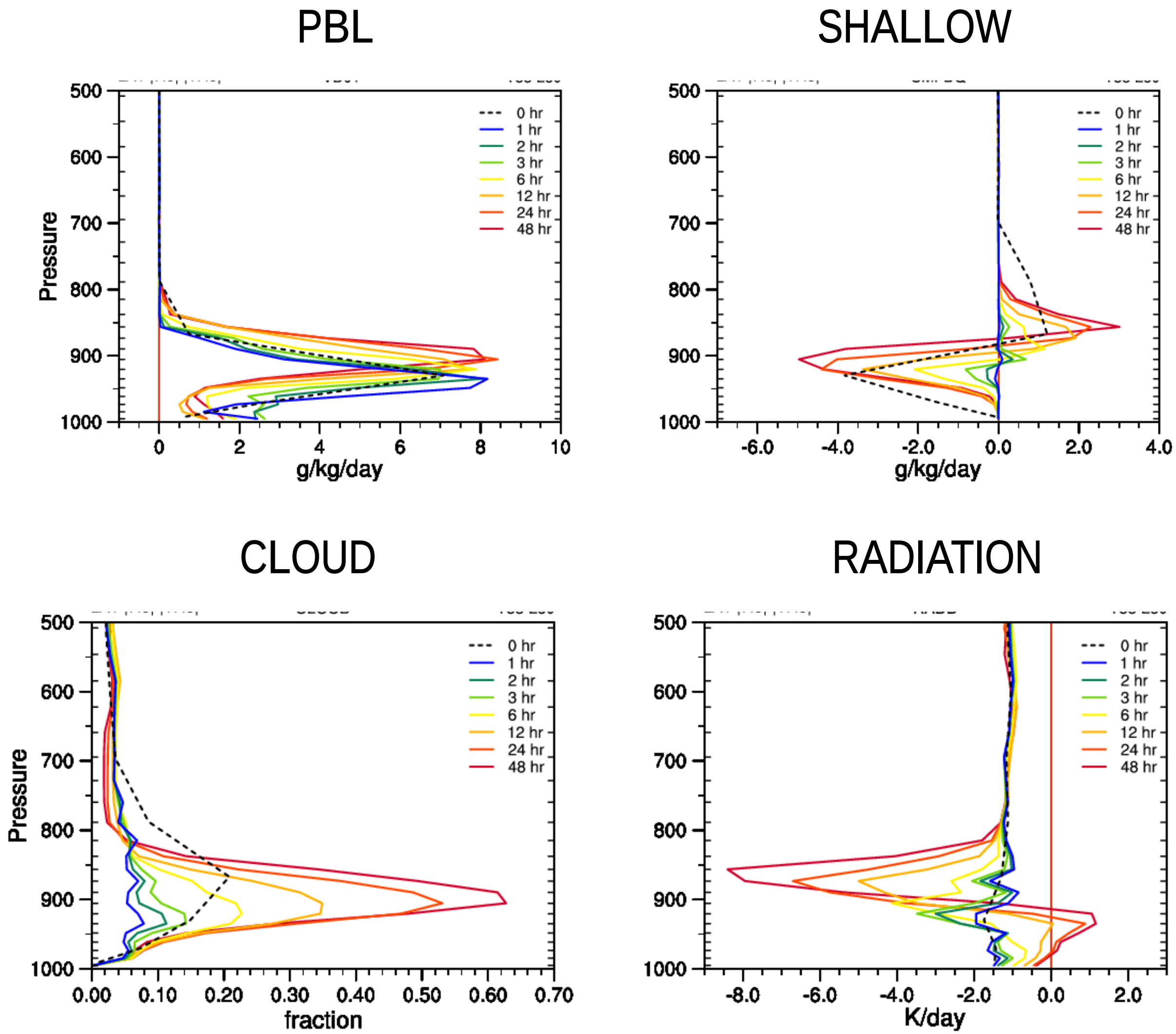
RELATIVE HUMIDITY
CLOUD
LONGWAVE RADIATION
T85 L26
T85 L30
T85 L60
PRESSURE (mb)
500
600
700
800
900
1000
0.0
0.2
0.4
0.6
0.8
1.0
fraction
-12
-9
-6
-3
0
3
6
9
K/day

PBL



MOIST PROCESSES




PBL
SHALLOW
CLOUD
RADIATION
Pressure
0 hr
1 hr
2 hr
3 hr
6 hr
12 hr
24 hr
48 hr
g/kg/day
fraction
K/day

$$h_{k+1} + pert > h_k^*$$

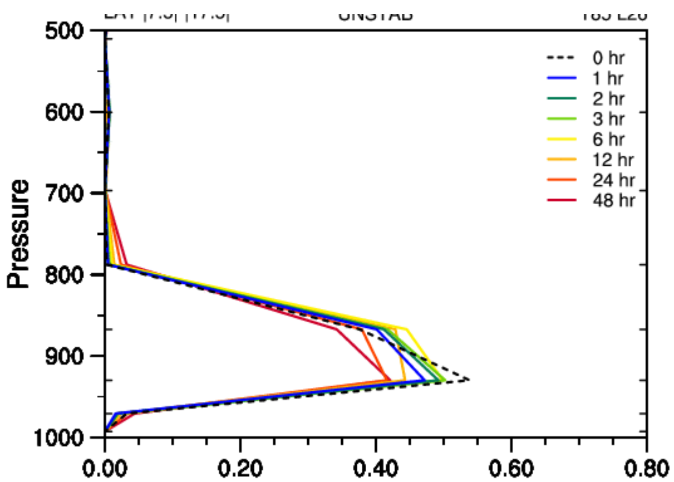
$$h = C_p T + g + Lq, \quad \text{moist static energy}$$

$$h^* = C_p T + g + Lq^*, \quad \text{saturated moist static energy}$$

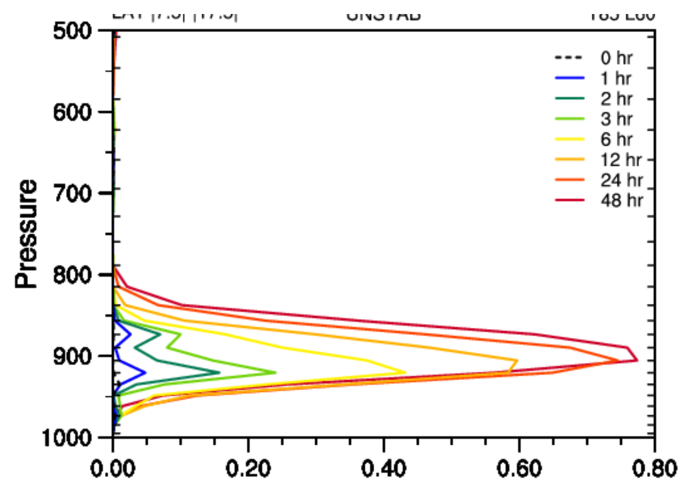
q^* is saturated specific humidity

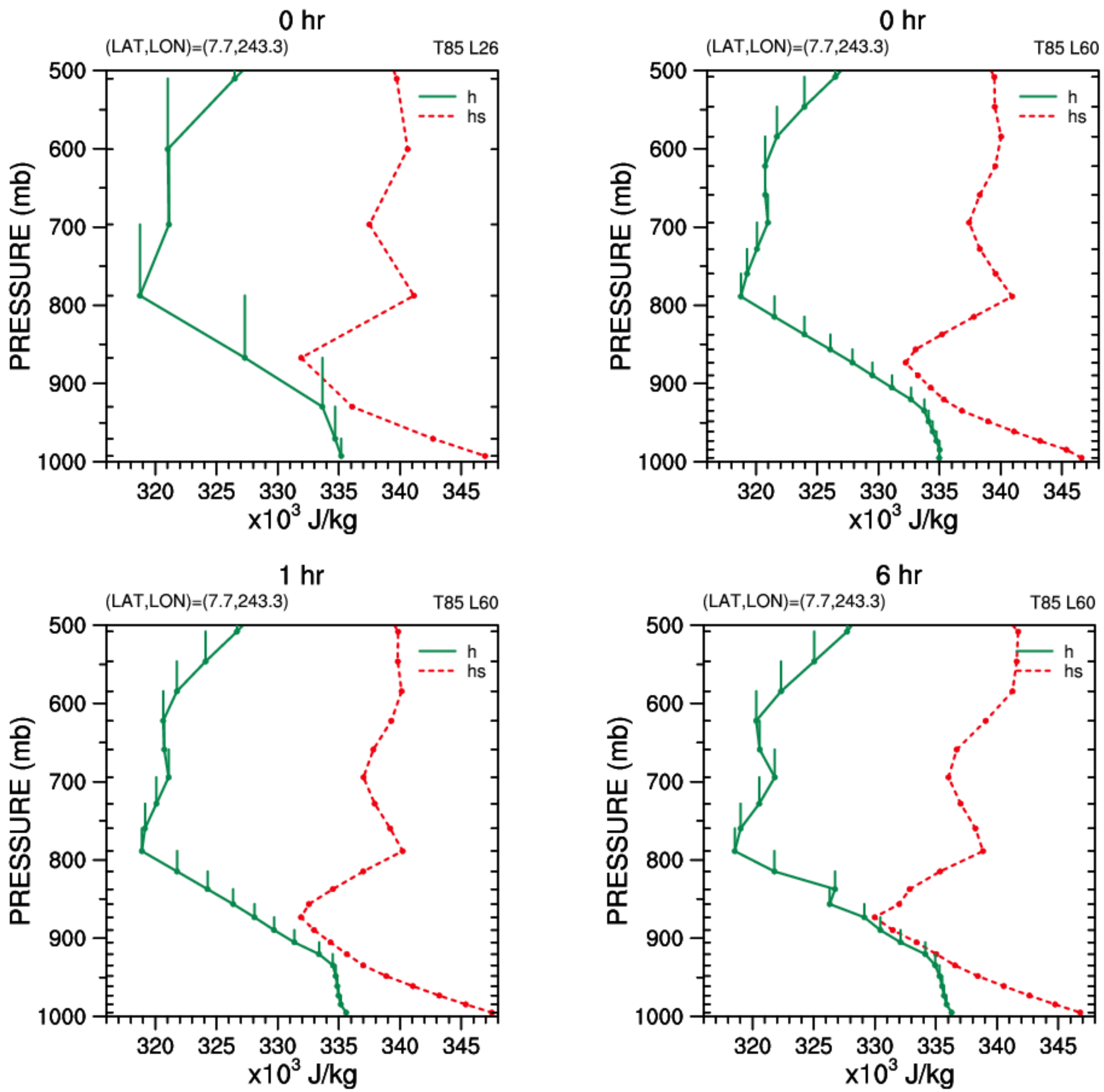
FRACTION OF UNSTABLE POINTS

26 levels



60 levels





0 hr
(LAT,LON)=(7.7,243.3)
T85 L26
0 hr
(LAT,LON)=(7.7,243.3)
T85 L60
1 hr
(LAT,LON)=(7.7,243.3)
T85 L60
6 hr
(LAT,LON)=(7.7,243.3)
T85 L60
h
hs
PRESSURE (mb)
500
600
700
800
900
1000
320
325
330
335
340
345
x10^3 J/kg

Evolution of 60-level simulation from a 26-level simulation

Shallow convection initially turns off
PBL continues to deposit water vapor between 850 and 900 mb
Relative humidity clouds increase between 850 and 900 mb
Longwave radiation cooling increases and destabilizes atmosphere
Shallow convection turns back on

BUT ATMOSPHERIC STATE IS NOT REALISTIC
CANNOT INCREASE VERTICAL RESOLUTION
NEED PARAMETERIZATIONS WHICH ARE NOT DEPENDENT ON GRID

In CAM3

2 degree Finite Volume is equivalent to T42 Spectral Transform

1 degree Finite Volume is equivalent to T85 Spectral Transform

Proportional relation does not hold at lower resolution

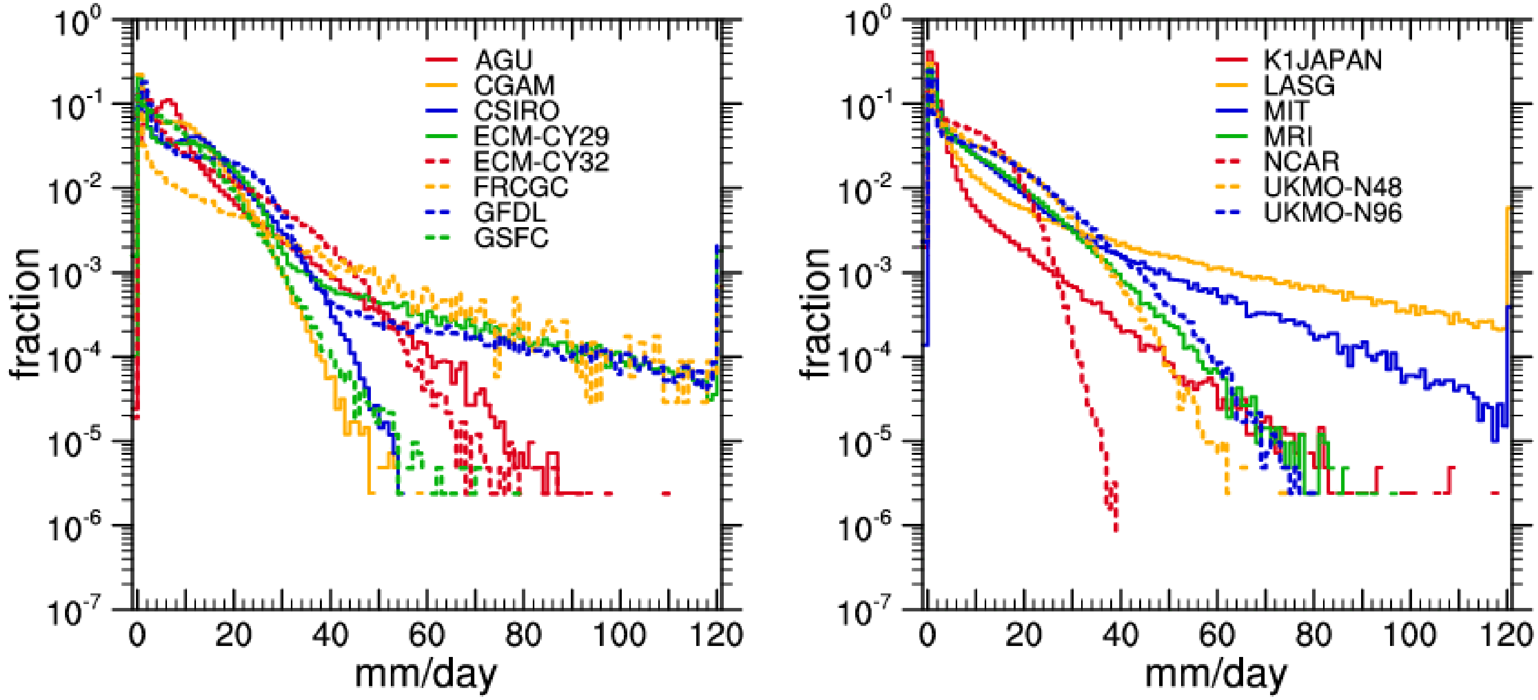
4 degree Finite Volume is not equivalent to T21 Spectral Transform

With aqua-planet can establish equivalent resolutions
of different dynamical cores

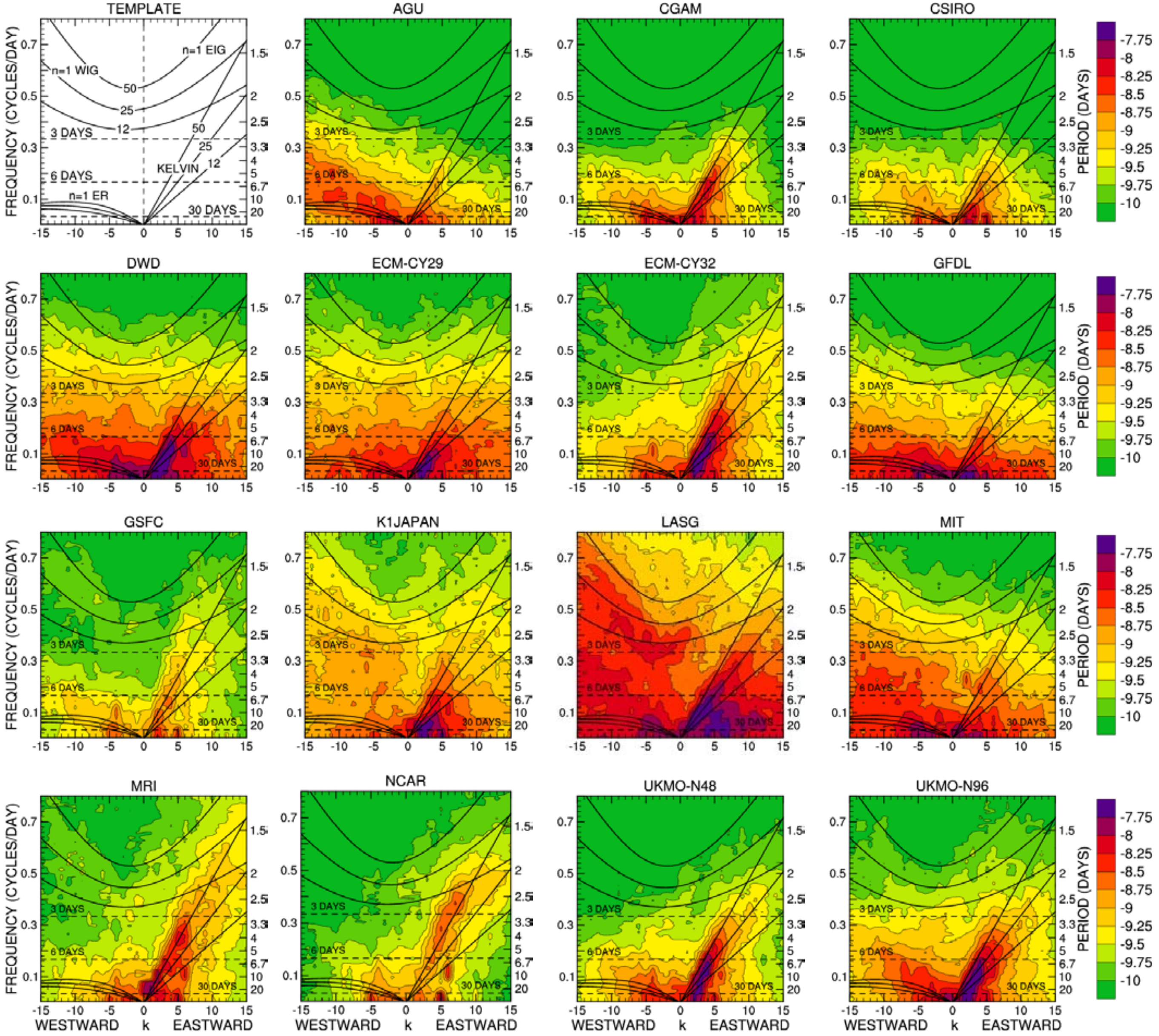
Has been used with additional cores
e.g. Mark Taylor with spectral element

BUT MUST USE SAME PARAMETERIZATION SUITE

PRECIPITATION AVERAGED TO 5 DEG GRID



CONTROL


TEMPLATE
AGU
CGAM
CSIRO
DWD
ECM-CY29
ECM-CY32
GFDL
GSFC
K1JAPAN
LASG
MIT
MRI
NCAR
UKMO-N48
UKMO-N96
n=1 EIG
n=1 WIG
n=1 ER
KELVIN
3 DAYS
6 DAYS
30 DAYS
FREQUENCY (CYCLES/DAY)
PERIOD (DAYS)
WESTWARD
k
EASTWARD
-7.75
-8
-8.25
-8.5
-8.75
-9
-9.25
-9.5
-9.75
-10

With aqua-planet can establish equivalent resolutions
of different dynamical cores
FOR UNFORCED COMPONENT

Has been used with additional cores
e.g. Mark Taylor with spectral element

But must use same parameterization suite

NEED TO REPEAT WITH DIFFERENT PARAMETERIZATION SUITE

NEED METHOD FOR FORCED COMPONENT