INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SMR/534-24

ICTP/WMO WORKSHOP ON EXTRA-TROPICAL AND TROPICAL LIMITED AREA MODELLING
22 October - 3 November 1990

"Specific Problems of LAM/Meso-Scale"
II.

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Please note: These are preliminary notes intended for internal distribution only.

The Use of Satellite Data as Proxy Data for Moisture and Diabatic Heating in the Tropics

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Why is it important to take account of diabatic heating ?

- Any satellite picture reveals regions of intense convective activity in the tropics
- A number of atmospheric features are closely connected with tropical diabatic heating
  - The 40-50 day oscillation
  - Tropical SST anomalies have local as well as extratropical influence- eg. the PNA teleconnection pattern
  - Impact of El-Nino events is well known and documented
  - The monsoon circulation

12 JAN 14 1990

Other aspects of tropical diabatic heating are equally important.

- 40-50 day oscillation in which convective processes play an important role.
  (Julian and madden 1971, 1972; Knutson et al, 1986)
- Equatorial waves may also play an important role in the oscillation
- Tropical Pacific SST anomalies have a significant extratropical impact particularly in the Pacific North-American sector

These aspects of tropical heating are still not fully understood.

A number of studies have explored the connection between tropical diabatic heating and equatorial waves. These indicate -

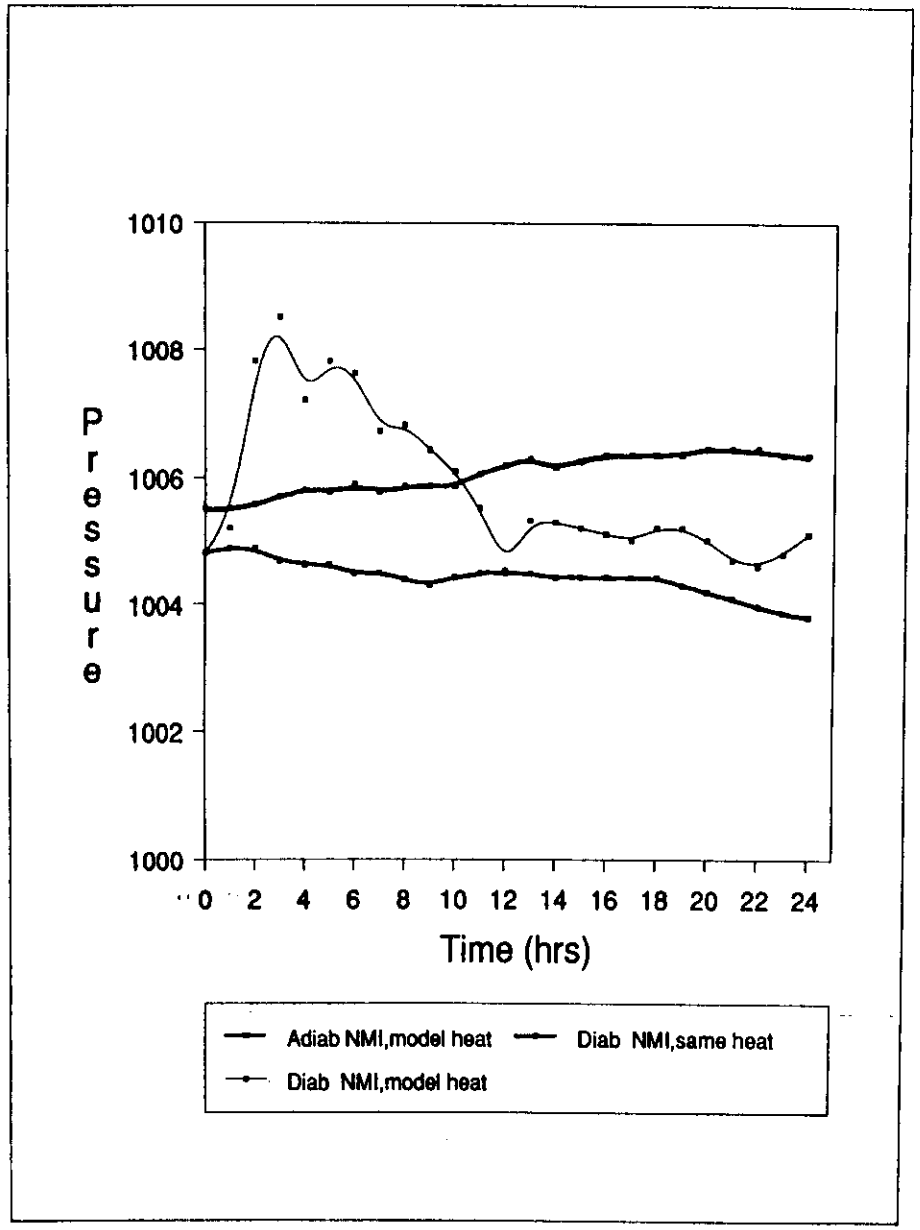
- Vertical modes whose profiles have baroclinic structure are favourably excited by tropical heating
- Tropical heat sources excite low frequency gravity modes, particularly Kelvin and Mixed Rossby-gravity modes.

Numerical models need to take proper account of tropical diabatic heating. This has following implications

- Tropical modes associated with diabatic heating need to be adequately analysed and modelled
- Divergence and moisture fields need to be adequately analysed and balanced
- Physical processes, particularly cumulus convection, have to be parameterised in a satisfactory manner
- Appropriate sea surface temperatures have to be used - given the important role of SST we might need to do data assimilation with a coupled air-sea model

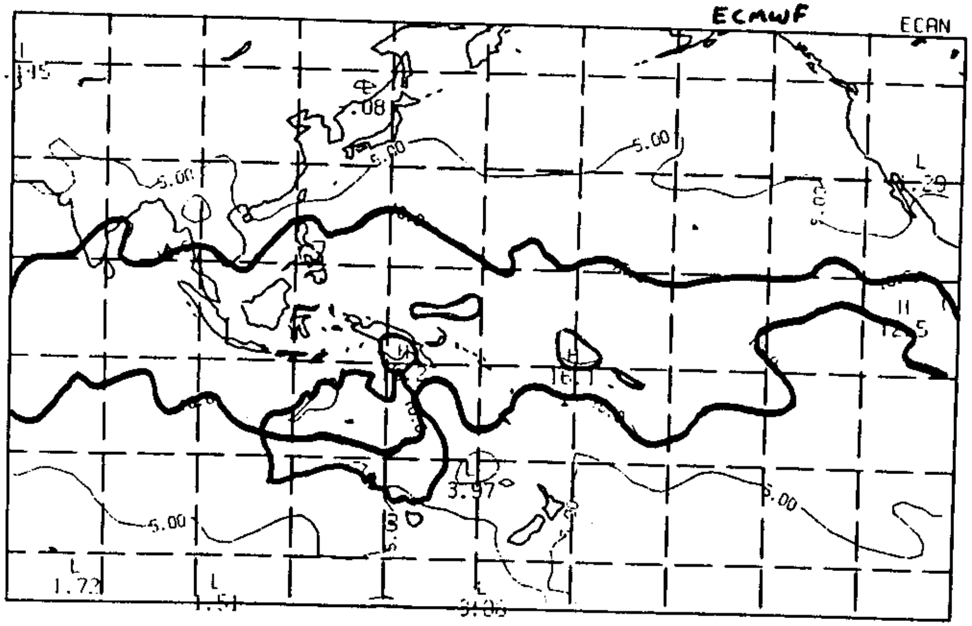
- None of these features are currently adequately handled in models
- This could partly explain the relatively poor performance of models in the tropics

- There are major problems in analysis and forecasts in the tropics.
- Here we will consider
  - Analysis of moisture and divergence.
  - inability to include information on diabatic heating.
- Inconsistency between moisture, divergence and diabatic heating leads to spin-up problem.
- Moisture date base in tropics is sparce and there are no direct measurements of heating.
- One possible way to alleviate these problems is to use satellite data as proxy data.

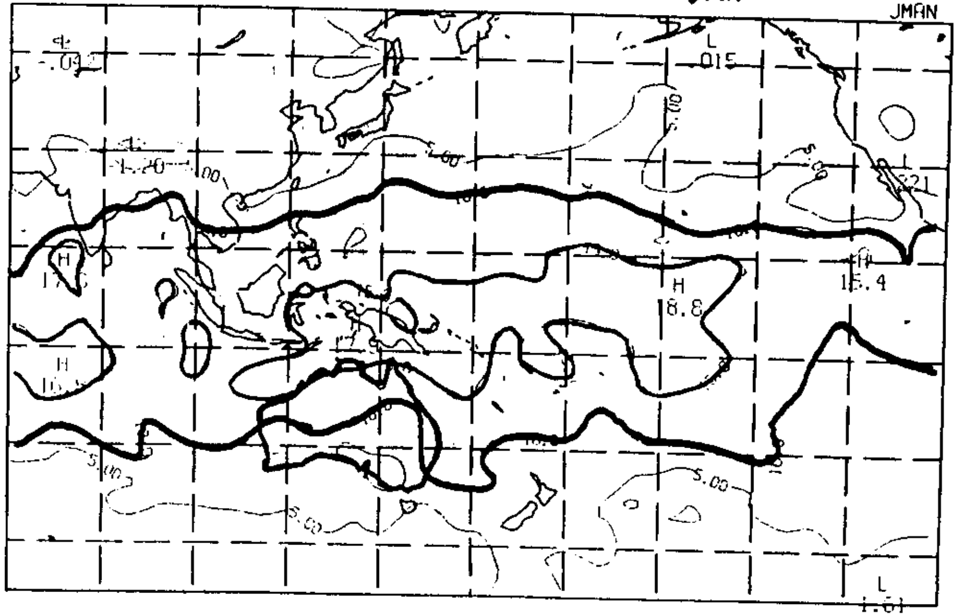


Mixing Ratio 850mb

ECMWF



JMA



Moisture bogus from GMS IR Imagery

Mills and Davidson, 1987

- Compute over 50k radius circles, for given Lat/Long locations, cloud population characteristics :

  (a) areal coverage of cloud tops within layers sfc-850, 850-700, 700-500, 500-300, < 300hPa
  -this defines CLOUD DEPTH and
  CLOUD AMOUNT (scattered or broken)

  (b) variability of cloud top temp in each layer :

  -this defines CLOUD TYPE (Cumulus or Stratus)

- For a large sample, group data with similar cloud characteristic and match with contemporary radiosonde dewpoint depression profiles :

  gives dewpoint dep. profiles for
  19groups = clr, bkn below 850hPa, sct below 850hPa
  + (4 higher layers * 2 cloud types * 2 amounts)

Moisture bogus from GMS IR imagery

(continued)

- APPLICATION : For a specified Lat/Long grid, compute cloud characteristic at each grid point, Determine group and assign dewpoint depression profile.

- LIMITATIONS :

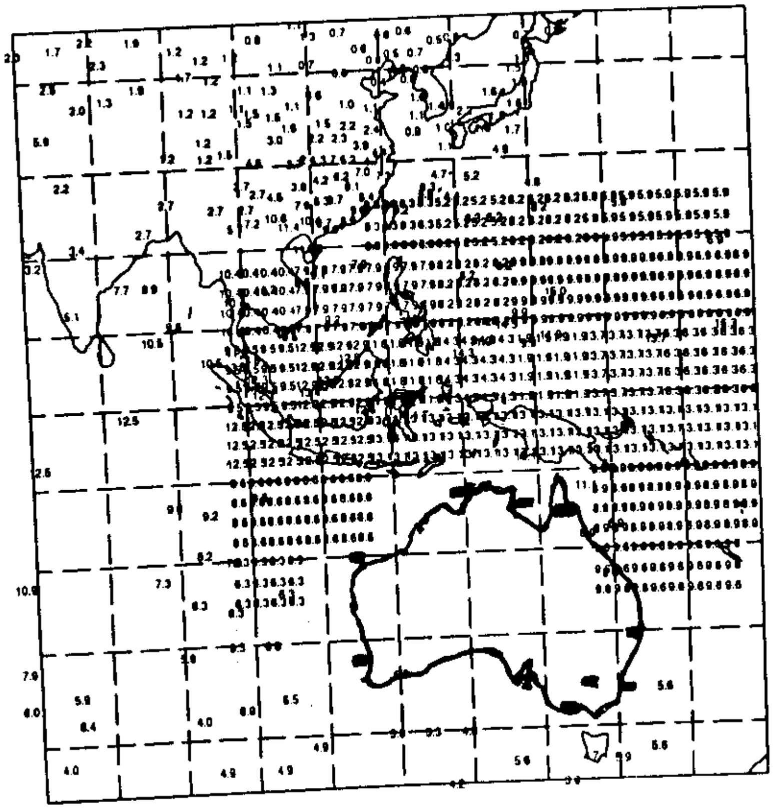
  (a) cannot detect moisture in non-saturated areas (so use TOVS)

  (b) clouds are assumed to be non-overlapping

  (c) no information from below cloud (so use surface obs.)

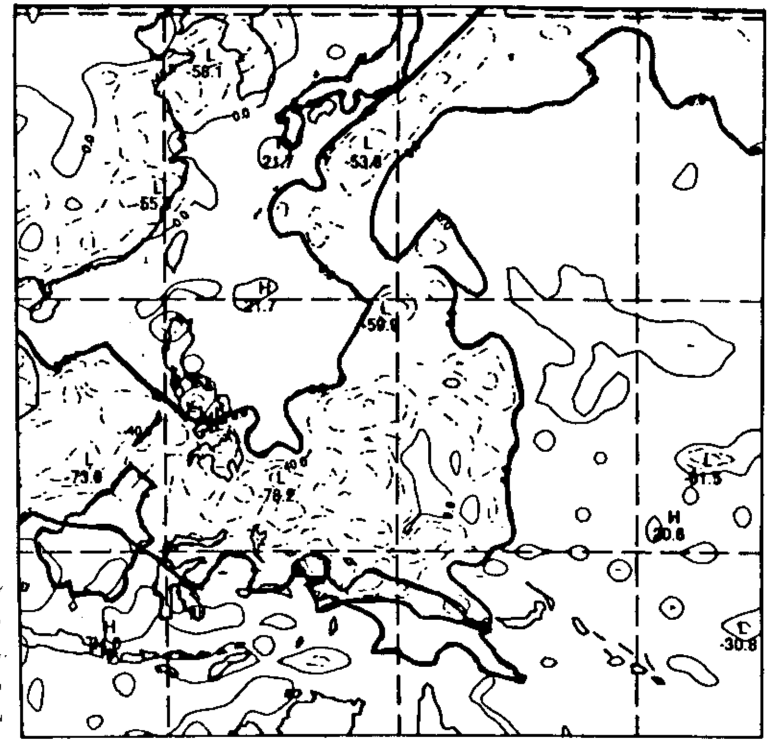
  (d) no stratification by latitude

  (e) simple statistical techniques have been used



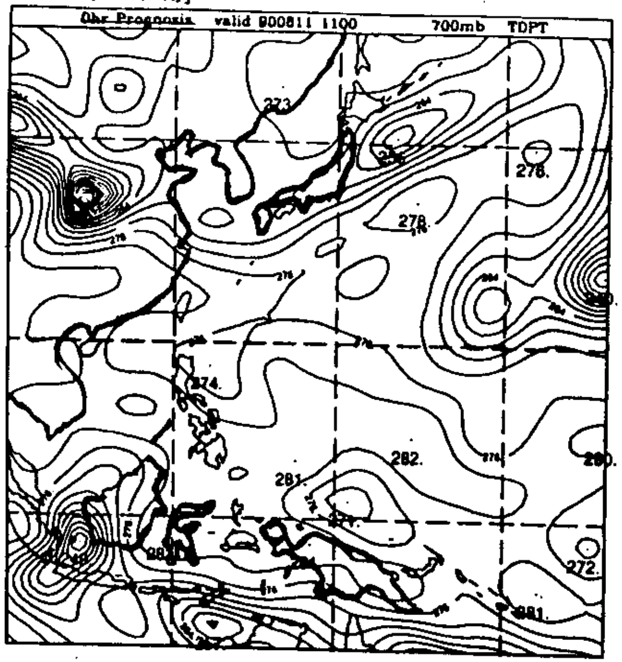
MIXR 900114 1100 850 MB

N.M.C. – DARWIN R.M.C. ANALYSIS



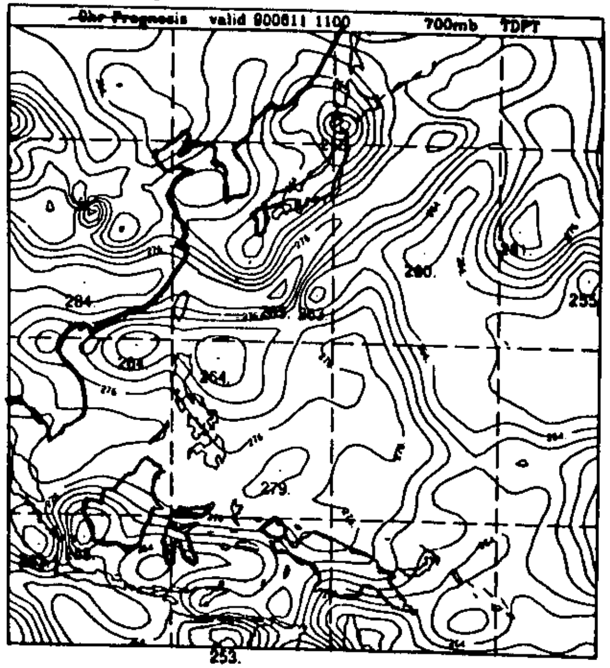
TROP HCLD 900611 1100

GASP ANALYSIS



GASP

REANALYSIS



Reanalysis with bogus moisture data

Diabatic NMI as used at ECMWF

- Model is integrated for 2 hours (from uninitialised fields) and diabatic terms are accumulated
- Time averages of diabatic terms over the two hour period are derived
- Resulting fields are filtered

Time filter	~~11~~ 5 hour period
Space filter	M20L10

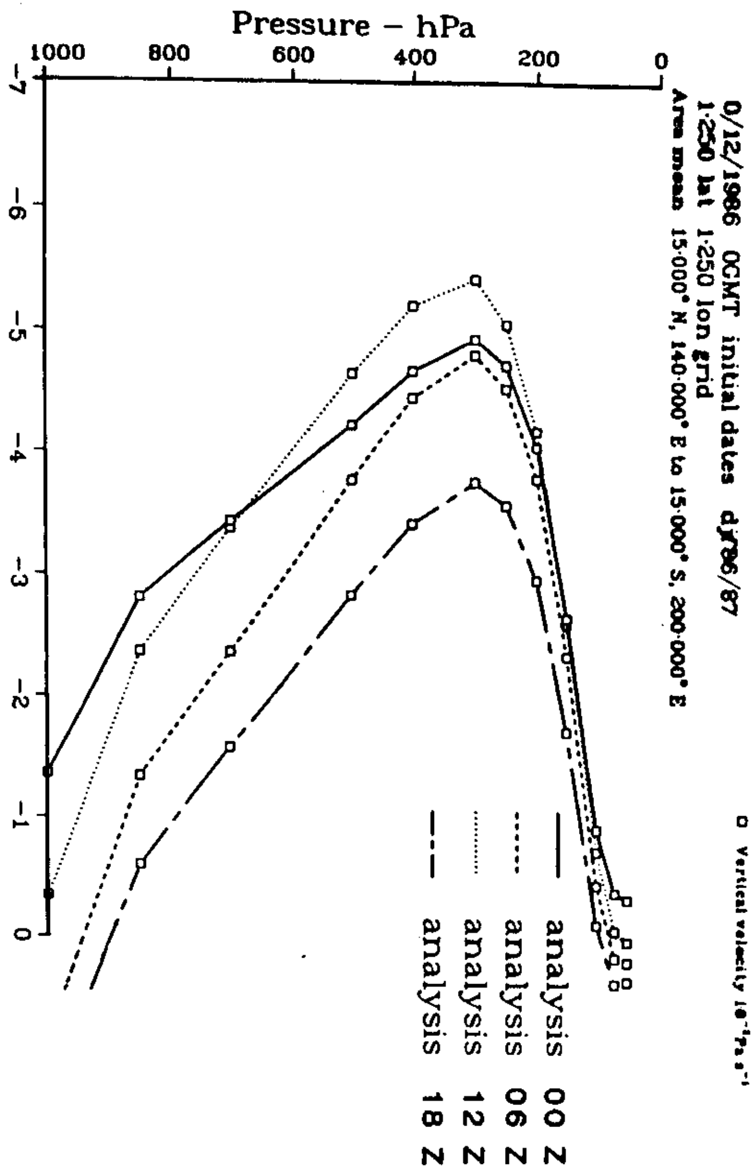
- Filtered fields are used as constant forcing during nonlinear NMI

Estimating of Heating Rates

- The procedure used relies on estimates of rainfall rate. To illustrate the procedure the rainfall is estimated using Arkin's formula

- The rainfall rate essentially a measure of vertically integrated heating rate at a particular location.

$$\int_{p_0}^{p_t} c_p \frac{\partial T}{\partial t}\, dp = L\dot{R}$$



INTENSITY and PROFILE
Method 1

- The vertical profile of heating is specified and intensity is evaluated

$$\text{If} \quad \frac{\partial T}{\partial t} = I\, H(p)$$

$$I = \frac{L}{c_p} \frac{\dot{R}}{\overline{H}}$$

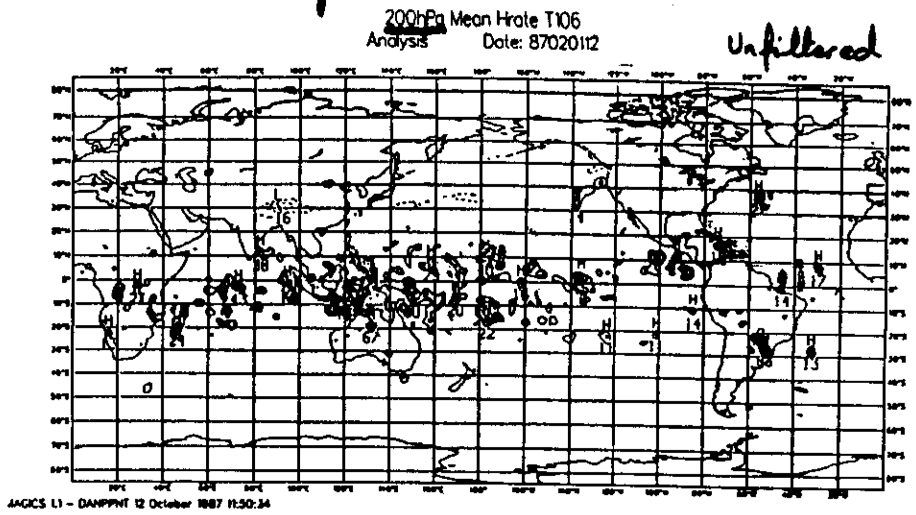
where

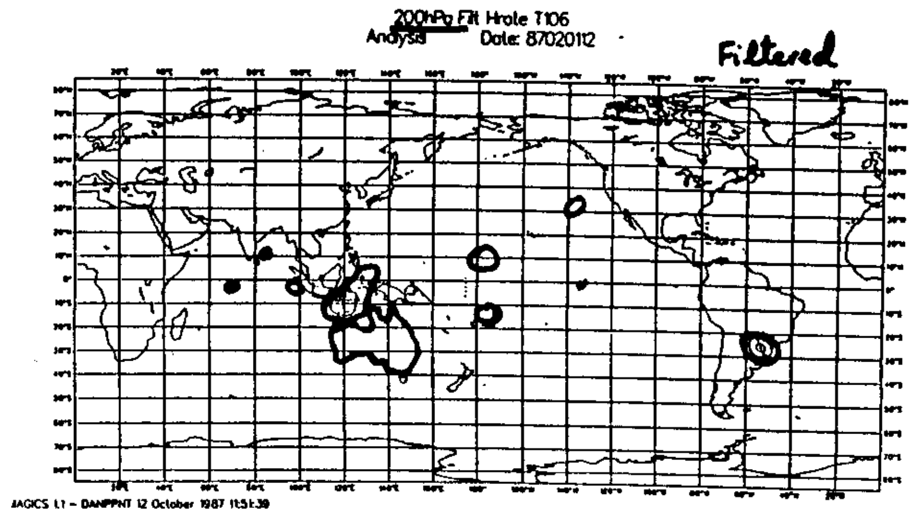
$$\overline{H} = \int_{p_0}^{p_T} H(p)\, dp$$

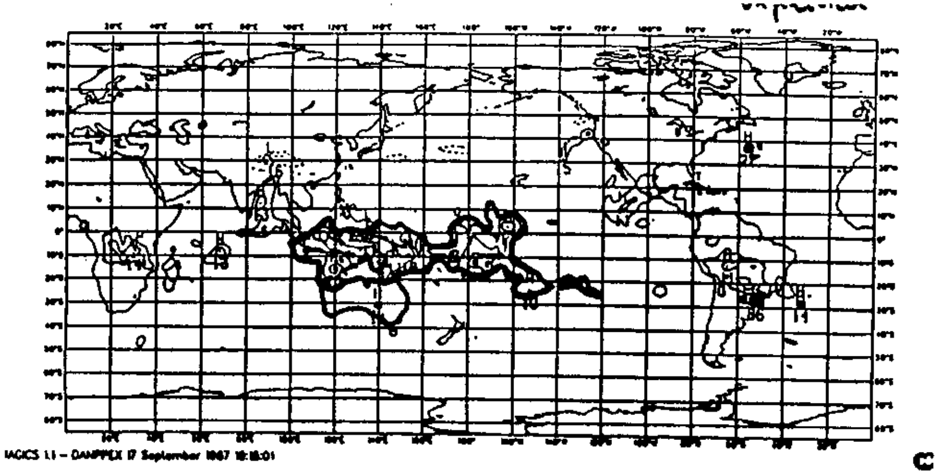
- The use of same specified vertical profile of heating is unsatisfactory for the following reasons -
  - Observational evidence indicates that profiles can vary with location.
  - Profiles also vary according to the stage in the life cycle of a convective system.
  - The specified profile may not be consistent with the parameterization used in the model.

INTENSITY and PROFILE
Method 2

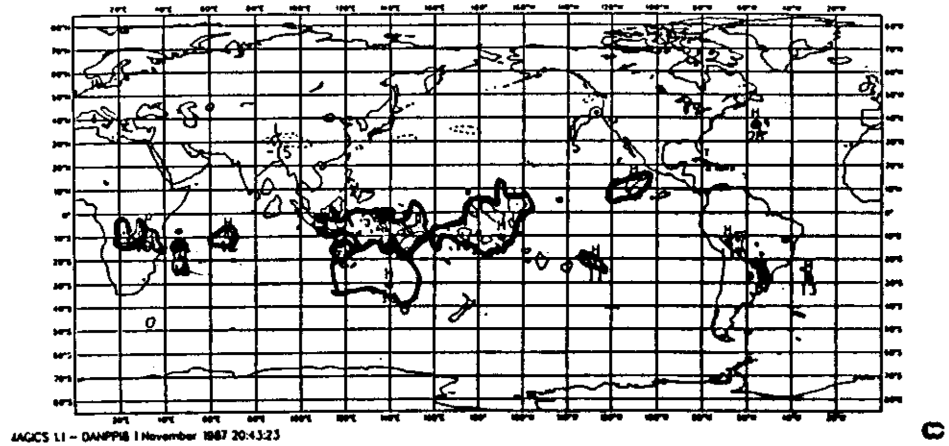
- Heating rates are derived from convective parameterization used in the model.
- For the KUO parameterization the procedure is as follows-
  - Evaluate $\dot{R}$
  - In the KUO scheme ,
    - Set moisture convergence to $\dot{R} * 2\Delta t$
    - set moistening parameter to <u>0</u>
- the scheme will now generate a heating rate that is consistent with both KUO parameterization and rainfall data



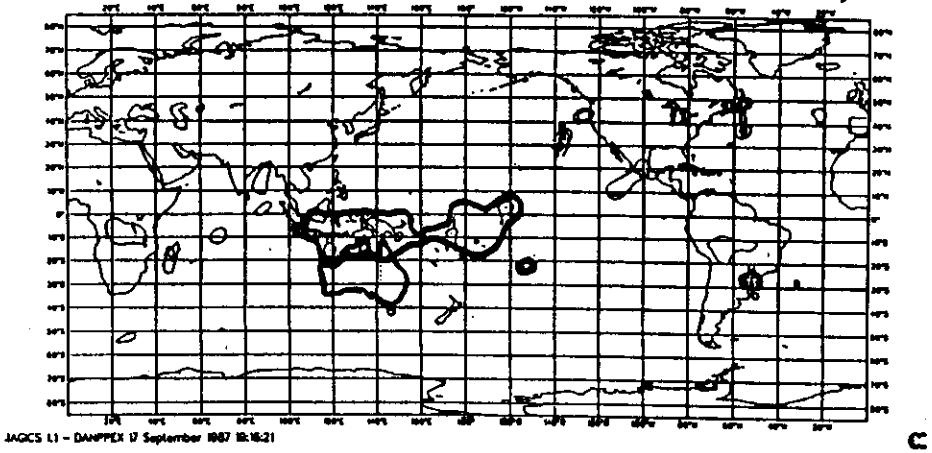




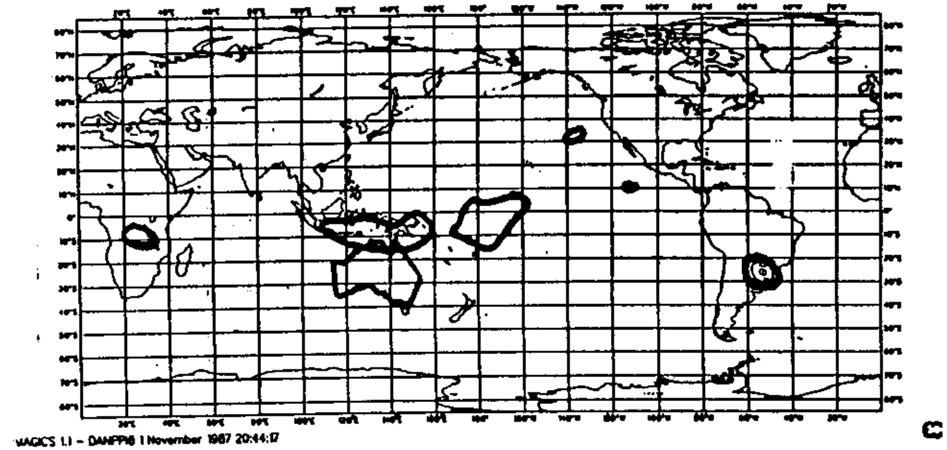
Analysis Date: 87020112 Unfiltered



200hPa Filt Hrate T106
Analysis Date: 87020112 FELTZ3.0, M40L40



200hPa Filt Hrate T106
Analysis Date: 87020112 Filtered



OLR based heating rates
Specified vertical profile

OLR based heating rates using Kuo parameterisation

Data Assim experiments

- Period 11z Jan 11 to 11z Jan 15 1990
- EXPERIMENTS
  - CNTL : Control as in Operational system
  - GMSQ : CNTL + Moisture bogus data at 11z and 23z
  - GMSI : GMSQ + Diabatic NMI with heating rates specified as above
  - GMSQ : GMSI + Heating rates specified during first 2 hours of model integration
- FORCASTS
  From 11z Jan 14 and 11z Jan 15

BMRC PREDICTION SYSTEM

GLOBAL / HEMISPHERIC SPECTRAL MODEL

9 LEVELS

σ = 0.991, 0.925, 0.811, 0.663, 0.500, 0.336, 0.189, 0.074, 0.009.

RHOMBOIDAL WAVE No. TRUNCATION
- OPERATIONAL R21
- EXPERIMENTAL R31

TIME INTEGRATION SEMI IMPLICIT

PHYSICAL PARAMETERIZATIONS

1. HYDROLOGIC CYCLE.
2. STABILITY DEPENDENT. MONIN – OBUKOV CONSTANT FLUX LAYER PARAMETERIZATION. (DELSOL ET AL,1972).
3. VERTICAL DIFFUSION (LOUIS,1979), SHALLOW CONVECTION (TIEDTKE,1984).
4. KUO CONVECTIVE PARAMETERIZATION (KUO,1974,ANTHES,1977)
5. RADIATIVE TRANSFER. VIA.
   GFDL VERSION OF LACIS AND HANSEN (1974) SHORT WAVE
   & FELS AND SCHWARZKOPF (1975) LONG WAVE.
6. CLIMATALOGICAL SPECIFICATION OF SST, LAND ALBEDO, SEA – ICE EXTENT.

Diagnostic clouds
Gravity wave drag

BMRC ASSIMILATION SYSTEM

NUMERICAL ANALYSIS

(a) UNIVARIATE STATISTICAL INTERPOLATION

OF INCREMENTS TO

SURFACE PRESSURE
TEMPERATURE
MOISTURE MIXING RATIO
ZONAL & MERIDIONAL WIND

WITHIN THE SIGMA,GAUSSIAN GRID

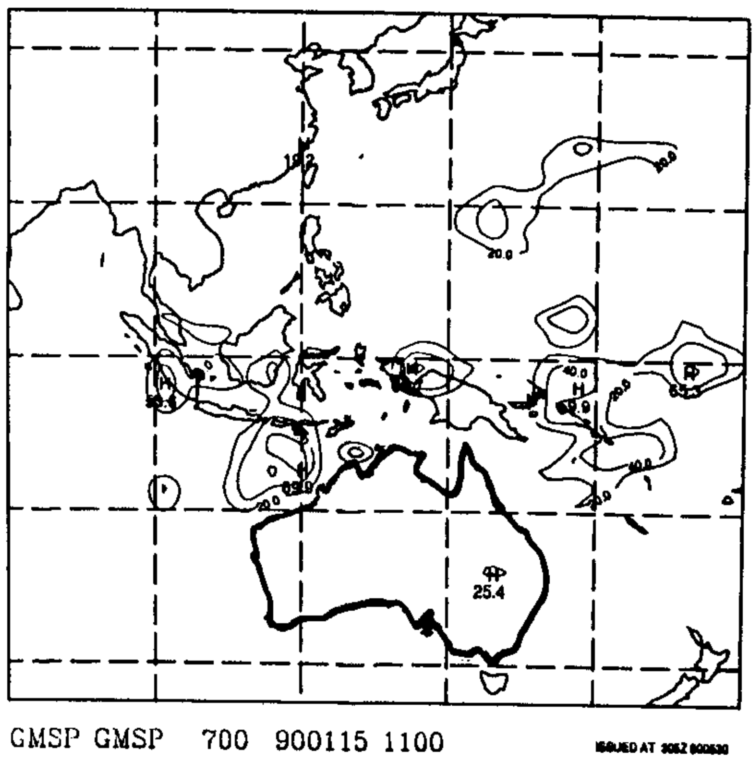
CO - ORDINATES OF THE SPECTRAL MODEL.

(b) GEOSTROPHIC CORRECTIONS TO THE WIND FIELD ARE DERIVED FROM INCREMENTS TO BOTH SURFACE PRESSURE & TEMPERATURE.

(c) MODEL SIGMA CO - ORDINATES ARE REDEFINED FOLLOWING SURFACE PRESSURE INCREMENTS.

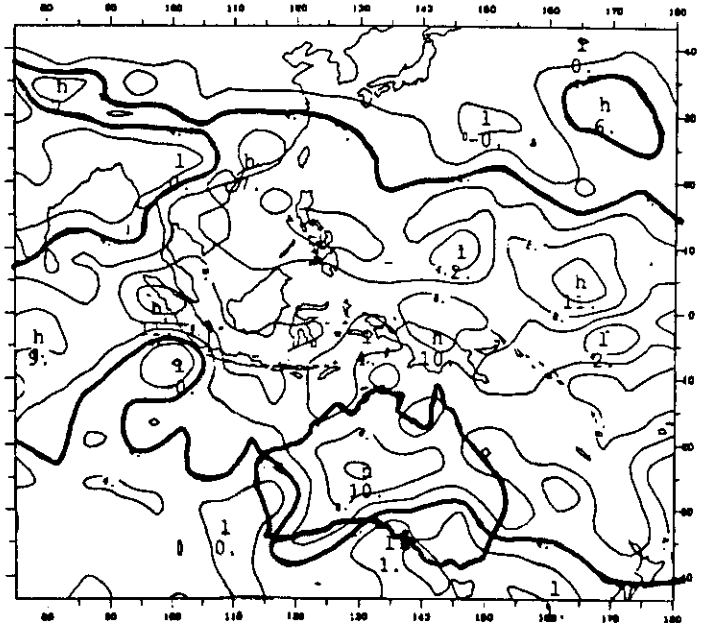
(d) NON - LINEAR NORMAL MODE INITIALIZATION.

Rainfall (mm.day^{-1}) 23Z JAN 14



kkp.o011411 ANALYSIS JAN 14

wcor day 1.0 q 700.0p
lat = -43.6: 43.6 lon = 75.0:180.0



CNTL

kkp.a011411

wcor day 1.0 q 700.0p
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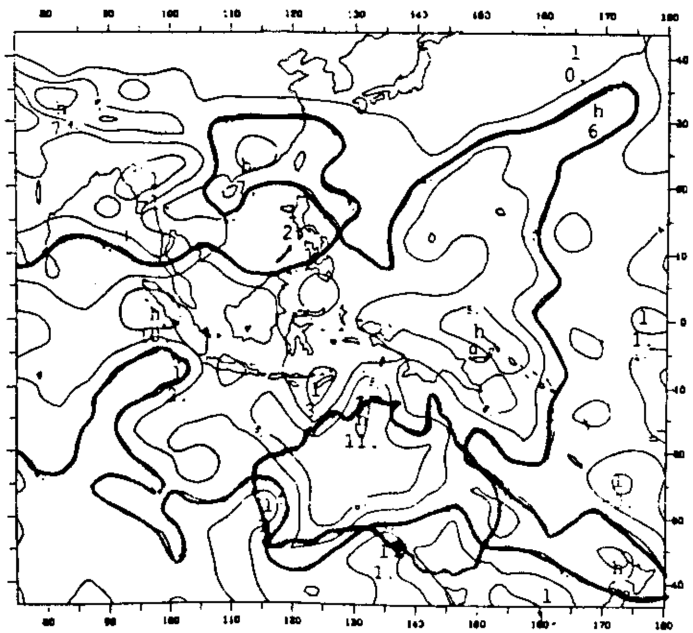
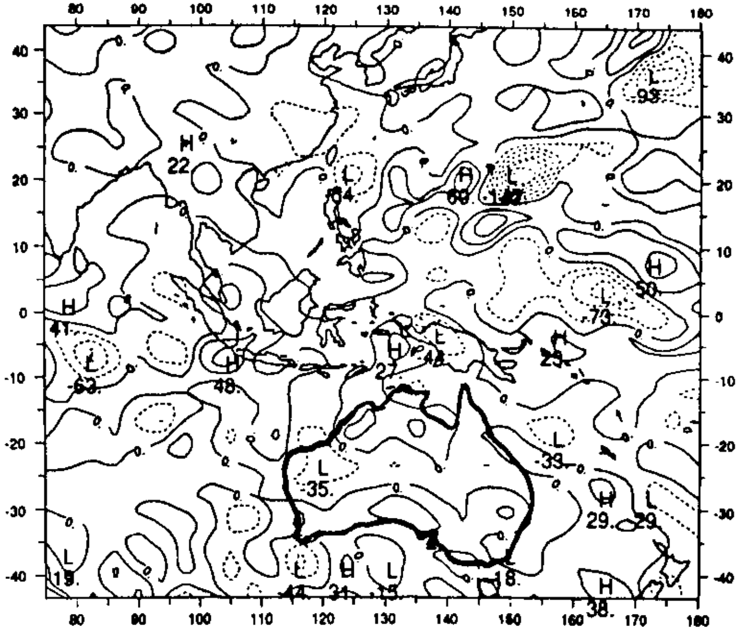


GMSQ

KKP.O011411 J∇·Vq 11Z JAN 14

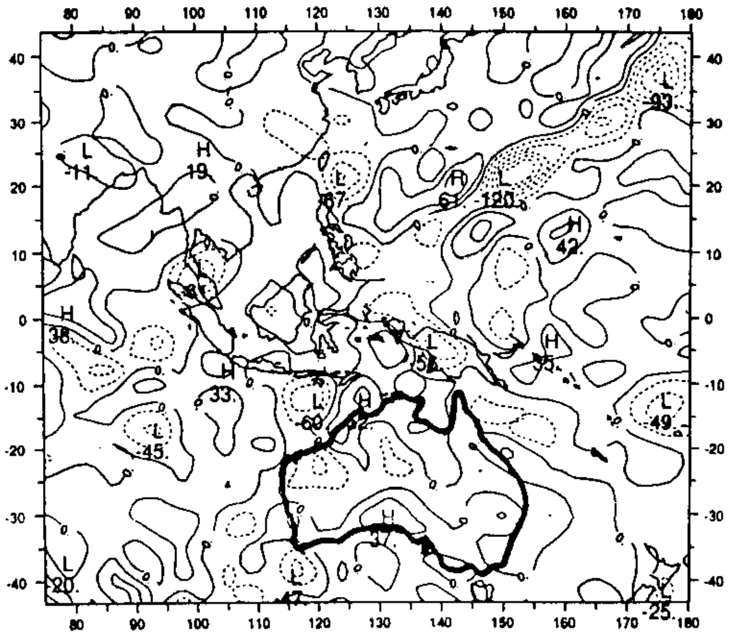
NMOD DAY 1.0 TOTDVQ



CNTL

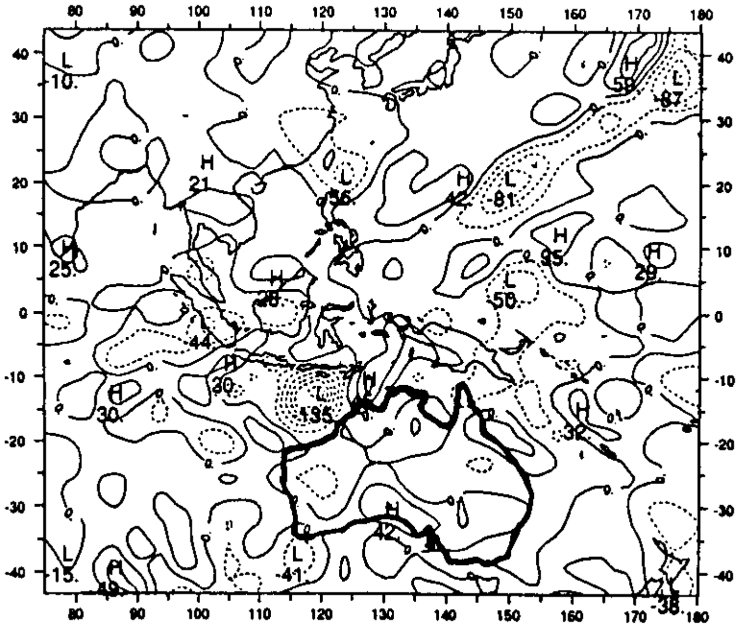
KKP.A011411

NMOD DAY 1.0 TOTDVQ



GMSQ

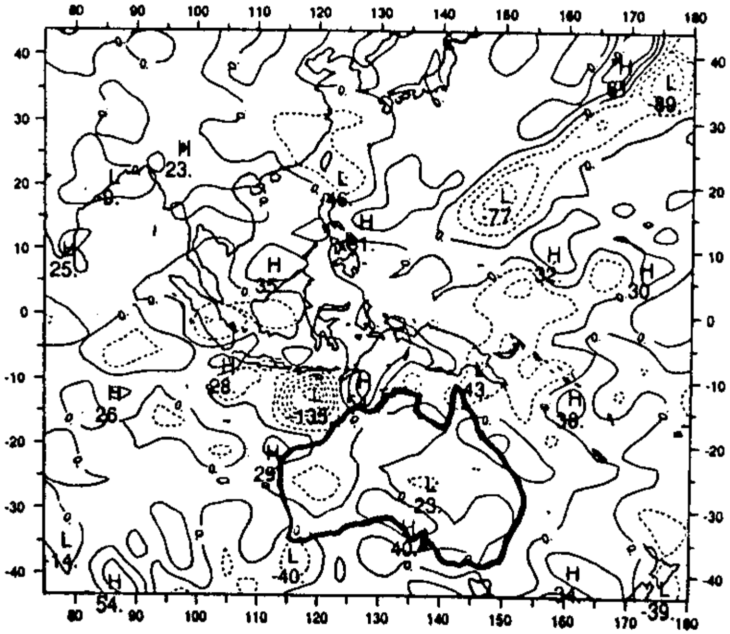
NMOD DAY 1.0 TOTDVQ



GMSI

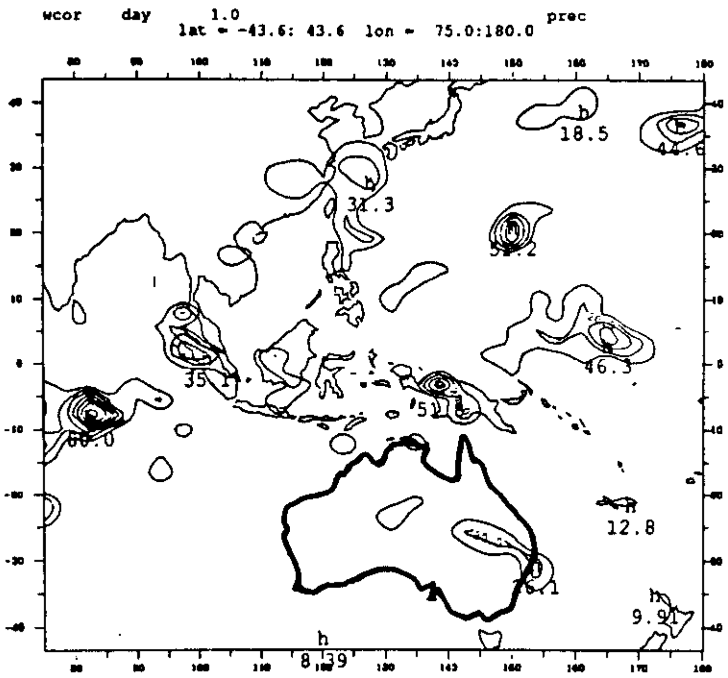
KKP.HAJ1411

NMOD DAY 1.0 TOTDVQ

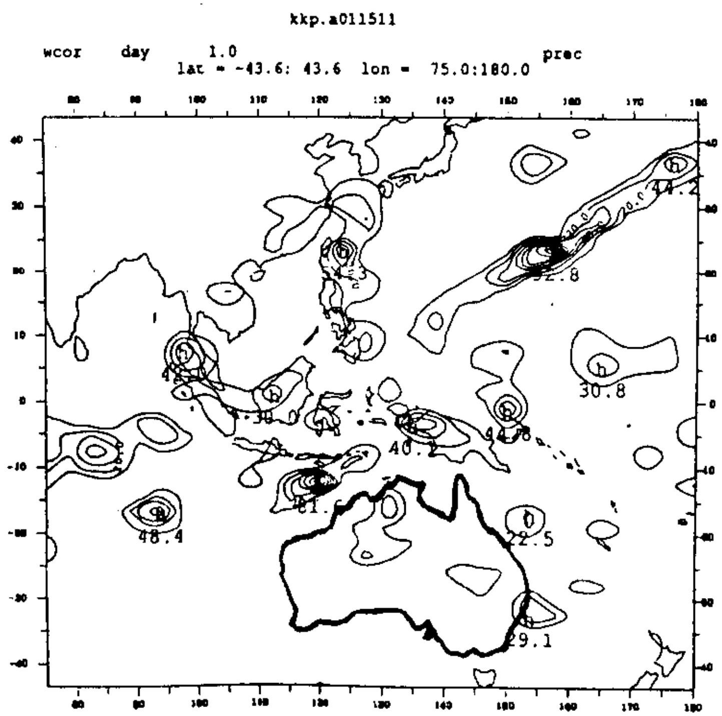


GMSH

Precipitation during assimilation JAN 15

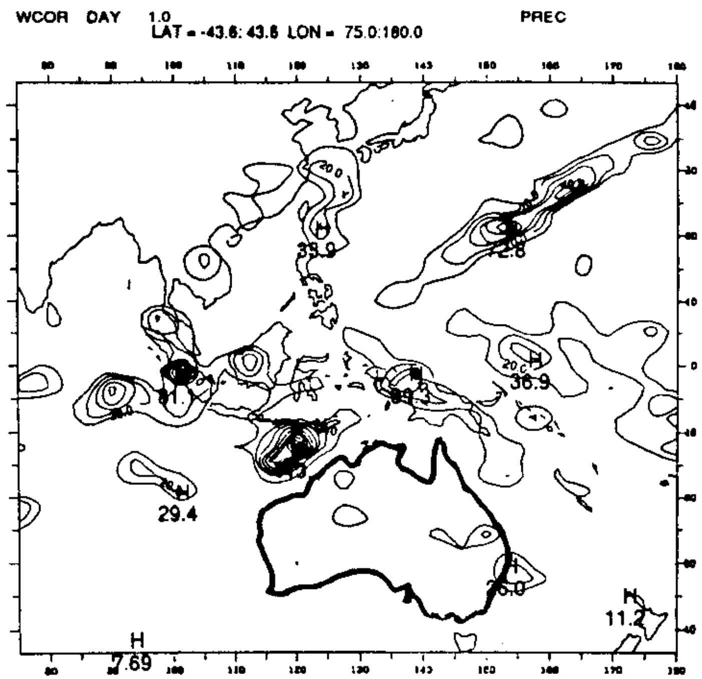


CNTL

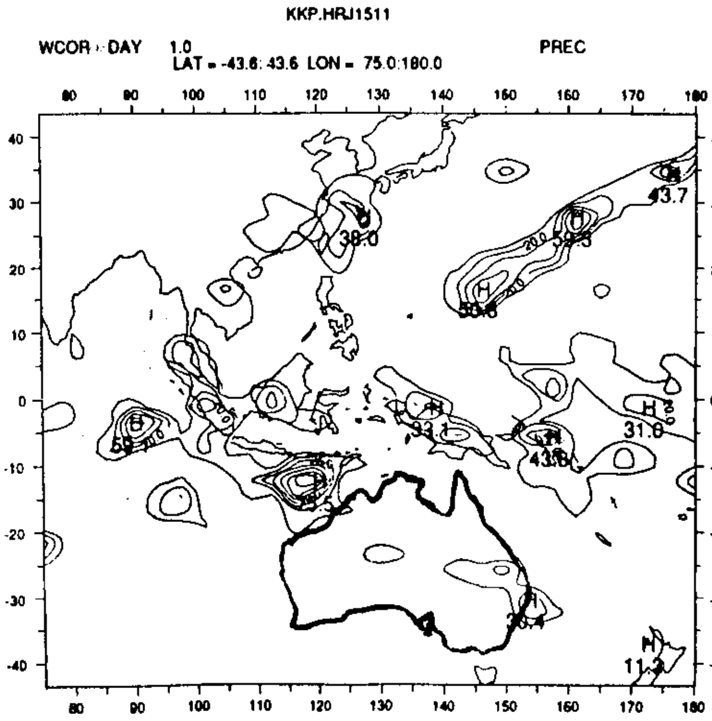


GMSQ

Precipitation during Assimilation JAN 15



GMSI



GMSH

KKP.OPJ1411 , DAY 1 FORC JAN 14

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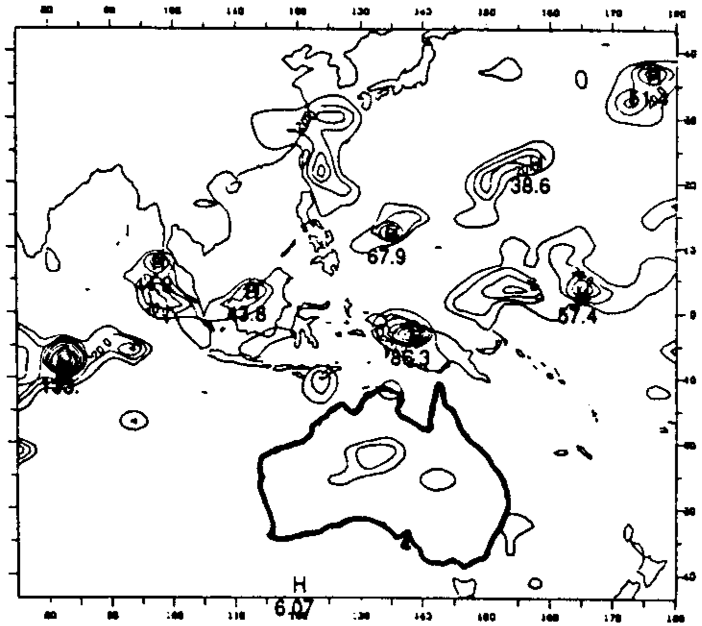

CNTL

KKP.GPJ1411 , DAY 1 FORC JAN 14

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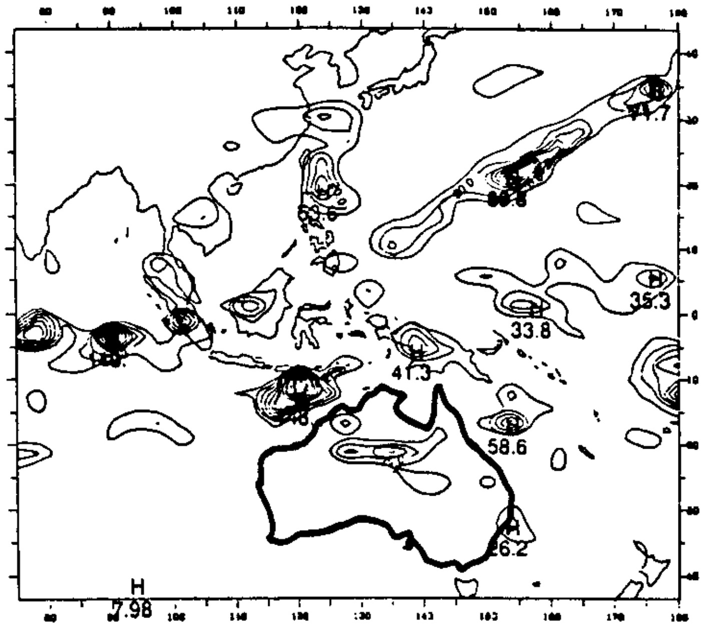

GMSI

KKP.P011411 , DAY 1

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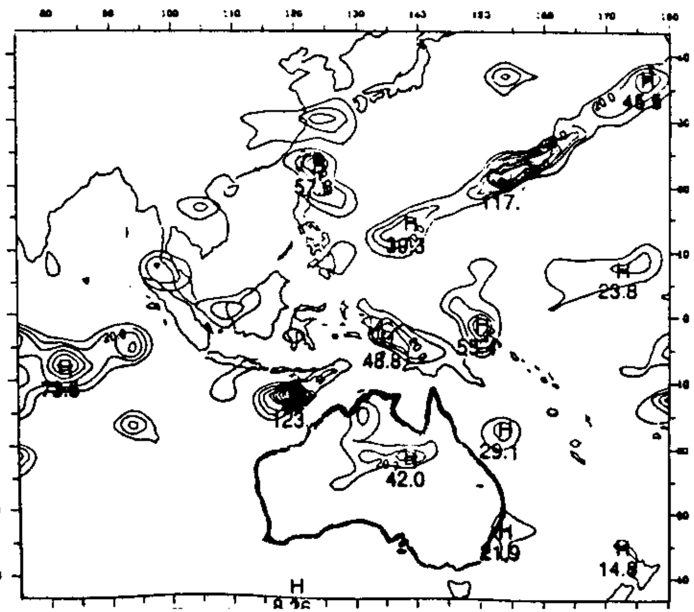

GMSQ

KKP.HRP1411

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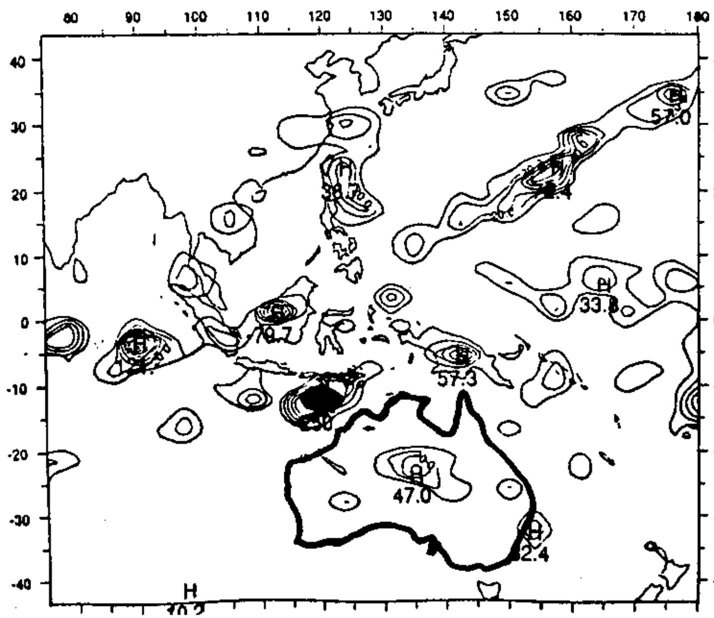
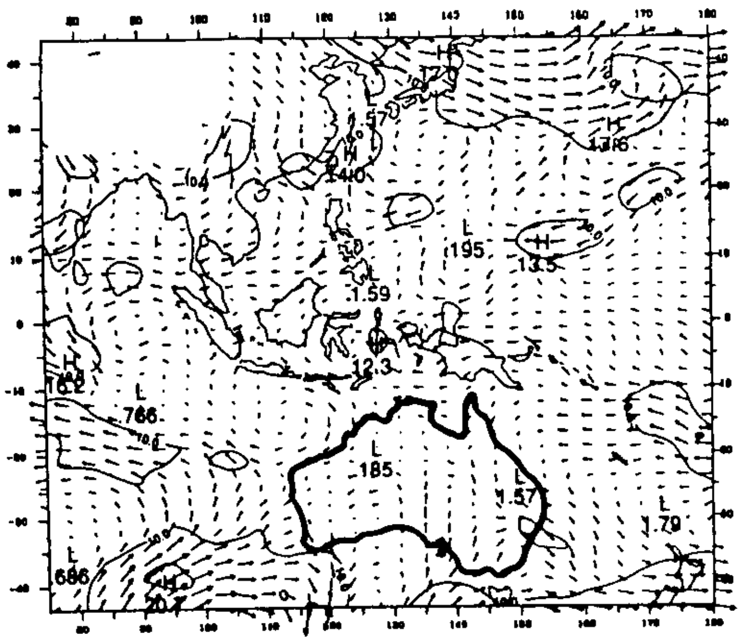


GMSH

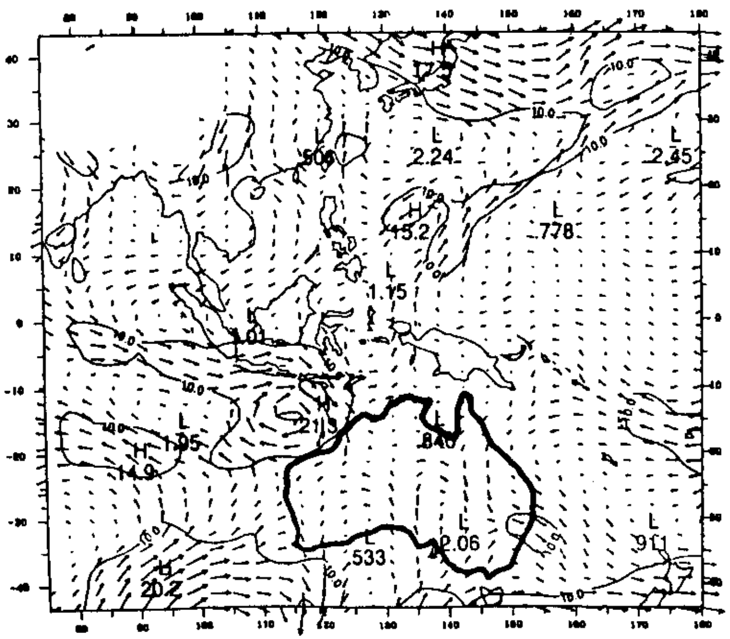
FORC DAY 1.0 LAT = -43.6: 43.6 LON = 75.0:180.0



CNTL

KKP:HPJ1411

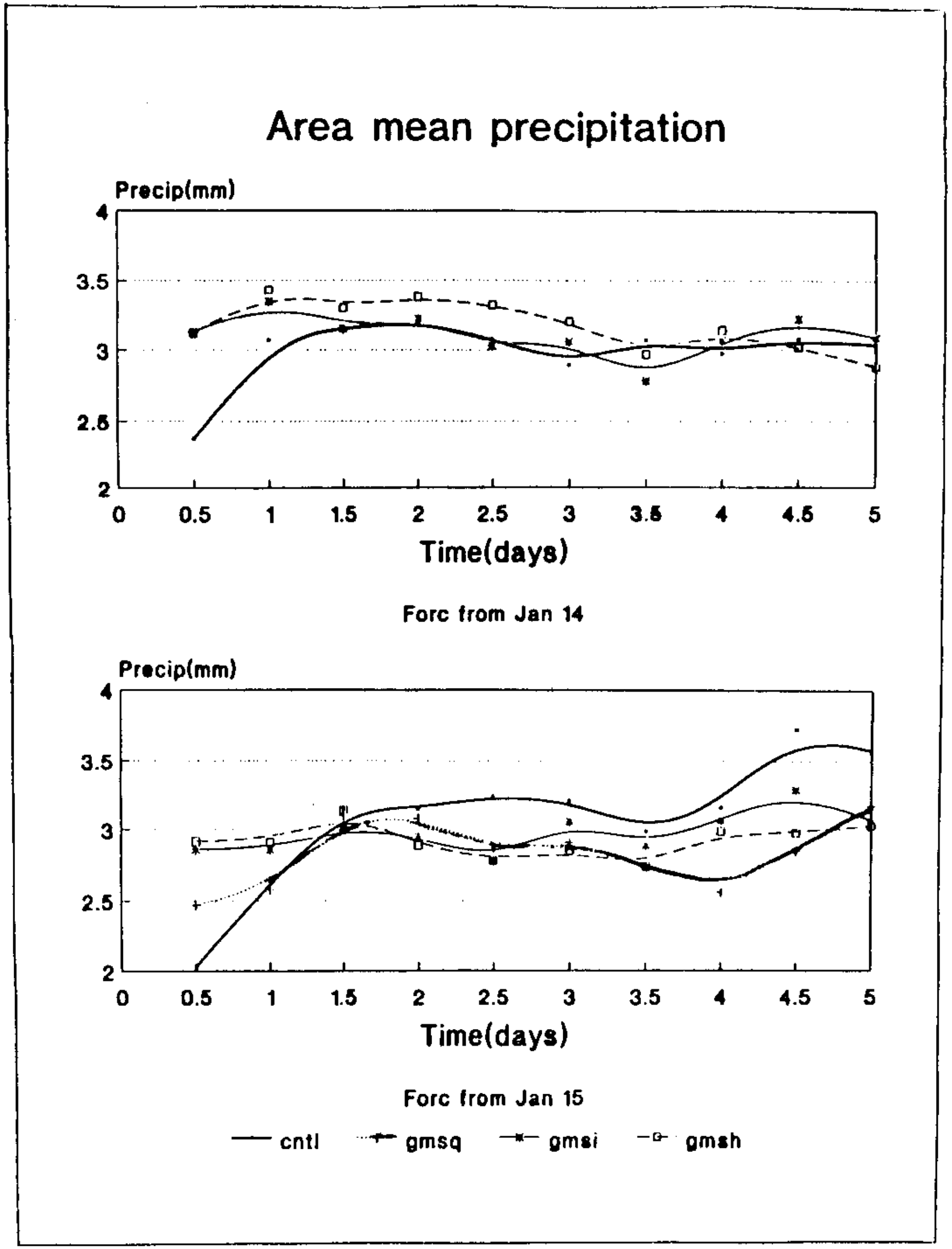
FORC DAY 1.0 LAT = -43.6: 43.6 LON = 75.0:180.0 WIND 850.0P

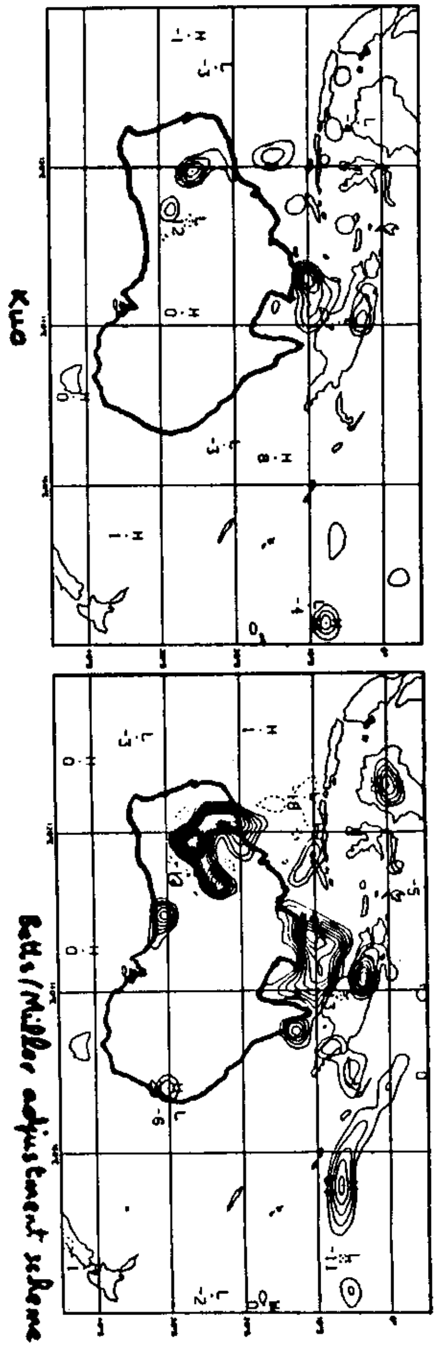


GMSH

CONTOUR FROM 0.00000E+00 TO 20.000 CONTOUR INTERVAL OF 10.000 PT(3,3)= 11.645

→ 0.200E+02 SCALING VECTOR





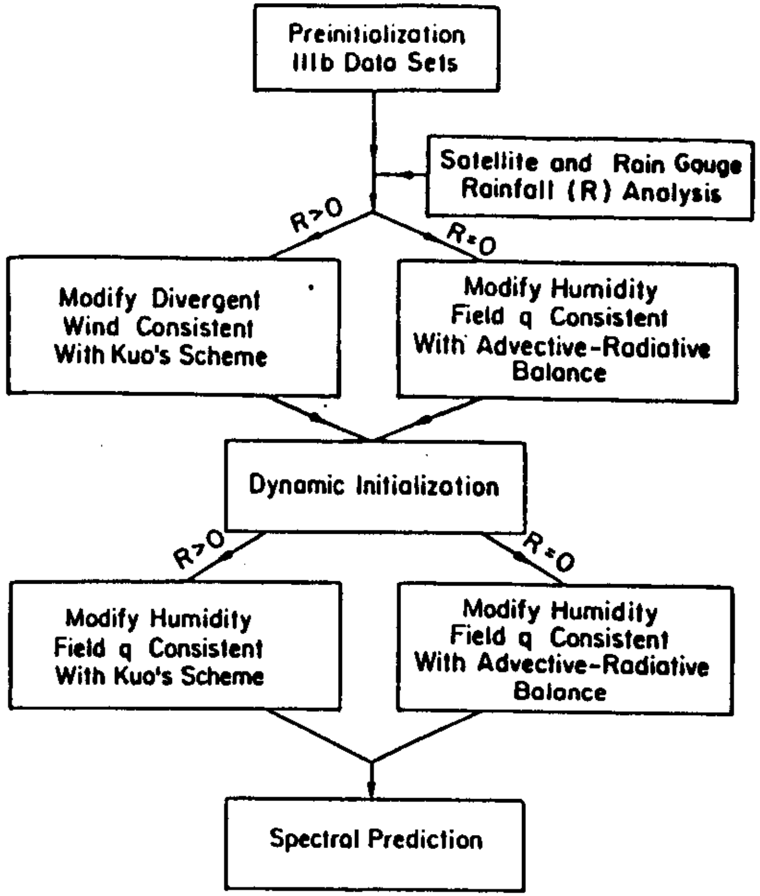


Figure 20

Krishnamurti, 1983

Betts-Miller adjustment scheme

- Scheme is based on adjustment towards quasi equilibrium profiles of T and q

$$\left.\frac{dT}{dt}\right)_{conv} = (T_R - T)/\tau$$

- Scheme is designed to ensure adjustment to more realistic structures (T_r, q_r) within relaxation timescale ~ 1hr such that
  - T_r is less stable than the moist adiabat in the lower troposphere and more stable above
  - q_r is computed so as to maintain sub-saturation in convective atmosphere
  - Sub saturation is obtained using a sub-saturation pressure difference

$$\mathcal{P} = p_* - p$$ where p_* is pressure to which parcel must be lifted to reach saturation

- The scheme guarantees that total enthalpy is conserved ie

$$\int_{p_B}^{p_T} (H_R - H)\,dp = 0$$

Moisture adjustment scheme

Precip rate from ADJ = $\int_{p_b}^{p_t} \frac{q_r - \bar{q}}{\tau} \frac{dp}{g}$ = ZRAIN

Precip rate from OLR = ZOBR

The technique requires computation of new reference profile such that

$$\int_{p_b}^{p_t} \frac{(q_r^* - \bar{q})}{\tau} \frac{dp}{g} \simeq ZOBR$$

The change $(q_r - q_r^*)$ is then added to $\bar{q}$ to give an adjusted moisture profile $\bar{q}^*$ so that

$$\int_{p_b}^{p_t} \frac{(q_r - \bar{q}^*)}{\tau} \frac{dp}{g} \simeq ZOBR$$

From direct inspection of T - ϕ diagram, it is possible to deduce a simple relation between $\delta\mathcal{P}(=\delta p_*)$ and δq

The following procedure is used

- Given ZRAIN, ZOBR (both>0) we compute

$$\Delta R = ZRAIN - ZOBR$$

- Convert ΔR to $\Delta \rho$ using empirical form

- Use linear profiles of $\Delta \rho$ such that maximum change in $|\Delta \rho|$ is at freezing level and no change at cloud top or bottom.

- Compute q_{vR}^{*} using $\rho_R^{*} = \rho_R + \Delta \rho$

- The modified moisture is

$$\bar{q}^{*} = \bar{q} + (q_{vR} - q_{vR}^{*})$$

Following combinations can occur

- ZRAIN $\gtrless$ ZOBR

  $\longrightarrow \bar{q}_M = \bar{q} \mp \delta q$

- ZRAIN < 0

  ZOBR = 0

  $\longrightarrow$ No change made to q

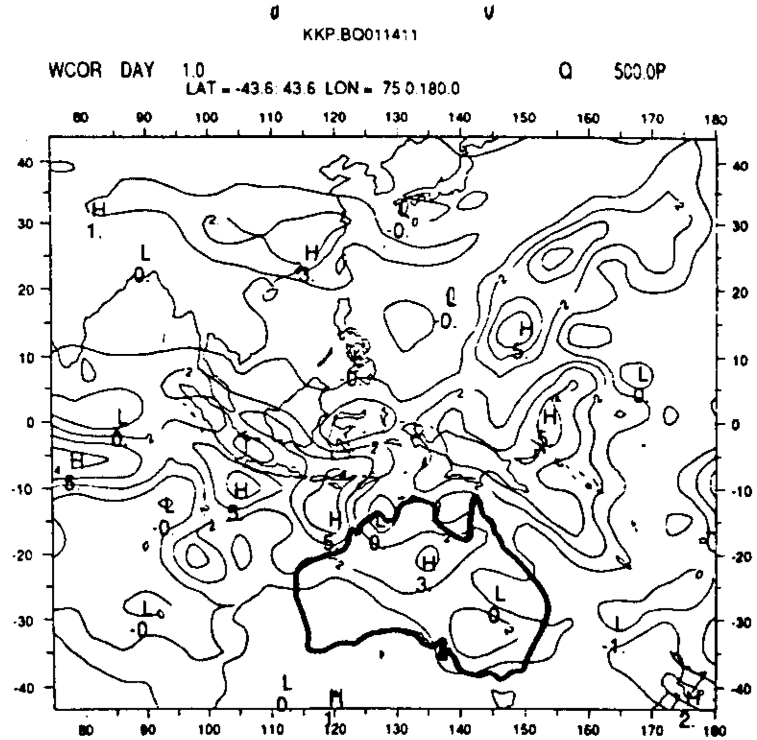
- ZRAIN = 0 ie no convection in model

  ZOBR > 0

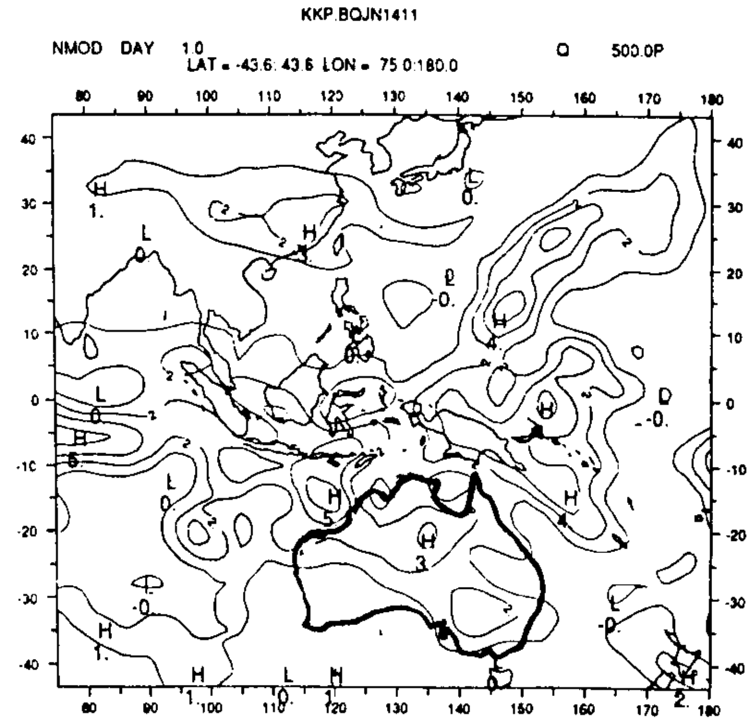
  $\longrightarrow$ Current scheme cannot cope with this

Some features of the scheme should be noted

- Only the moisture field is modified - the temperature remains unchanged.
- 'Observed' rainfall is assumed to be convective rainfall. This is approx. true in the tropics but not in midlatitudes.
- Scheme is only applied in the tropics - this is consistent with above assumption and the use of OLR based rainfall which is only valid in the tropics
- Moisture adjustment will only occur in regions where convection is diagnosed in the model



Before Moisture Init.



After Moisture Init.

Mixing Ratio Analysis 11Z Jan 15

KKP.BQ011511

WCOR DAY 1.0 Q 500.0P
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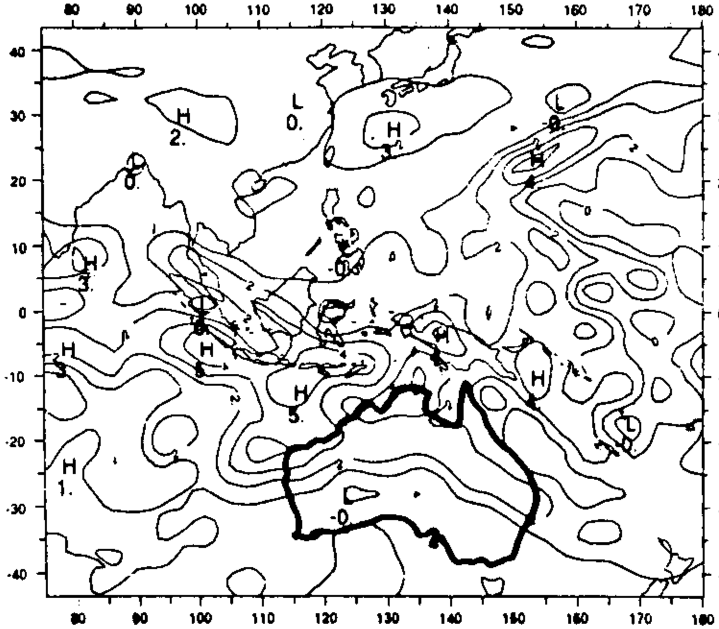

Before Moisture Init.

KKP.BQJN1511

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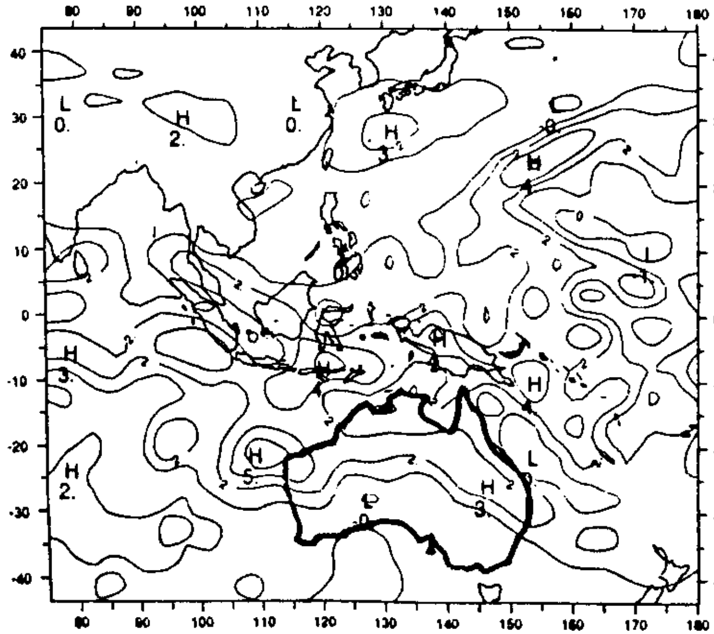
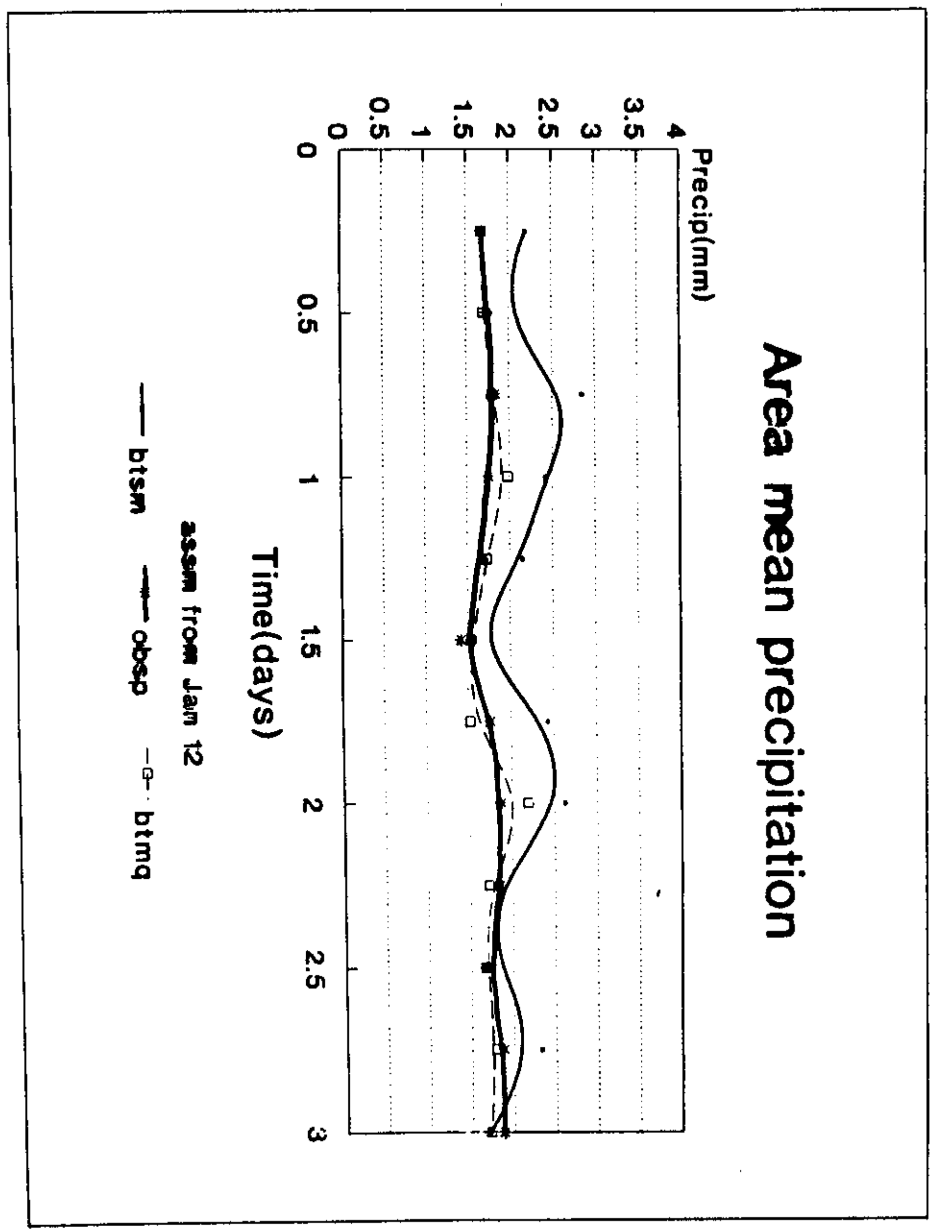
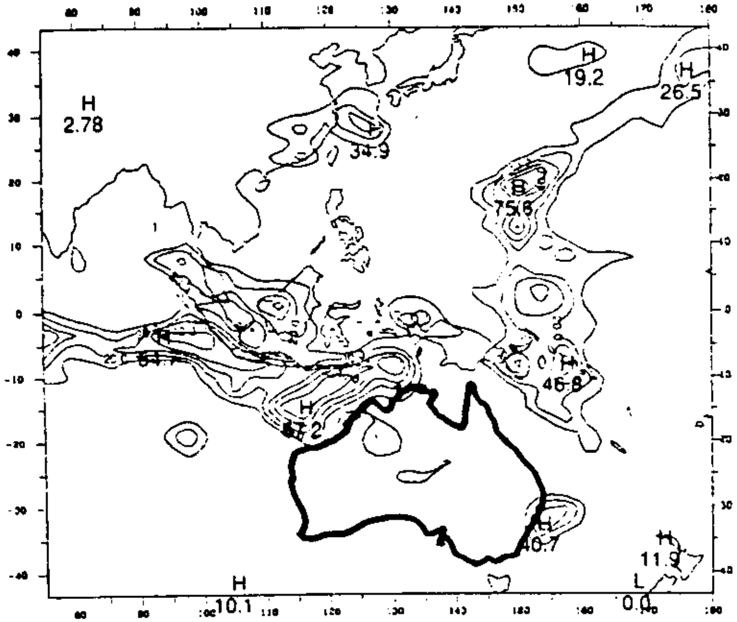


After Moisture Init.



WCOR DAY 1.0 PREC 0 11Z Jan 15
LAT = -43.6: 43.6 LON = 75.0:180.0



B-M

KKP.BQ011511

WCOR DAY 1.0 PREC
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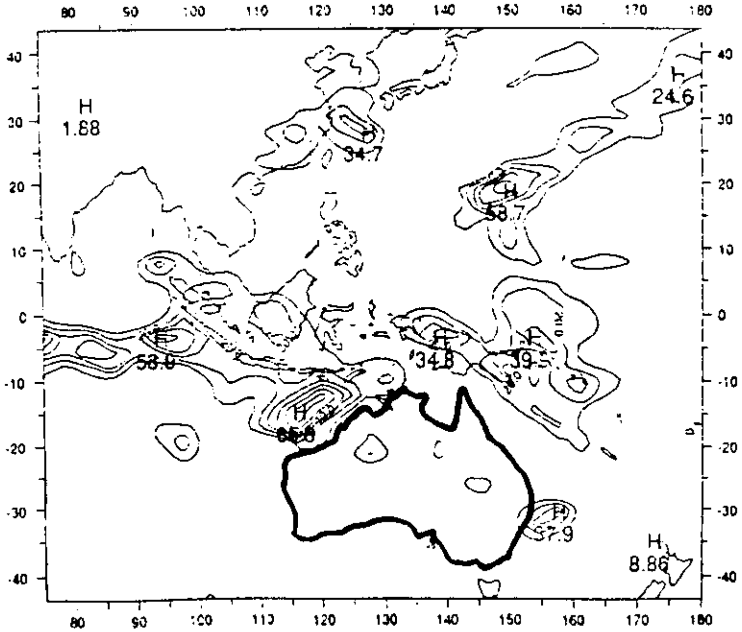

B-M + Madj

KKP.BRP1411 , DAY 1 Forecast Jan 14

FORC DAY 1.0 PREC
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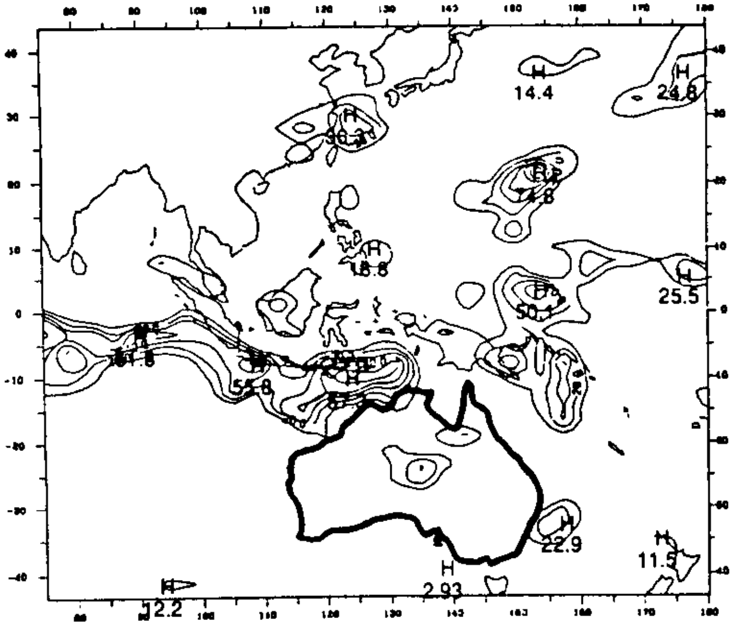

B-M

KKP.BQPJ1411

FORC DAY 1.0 PREC
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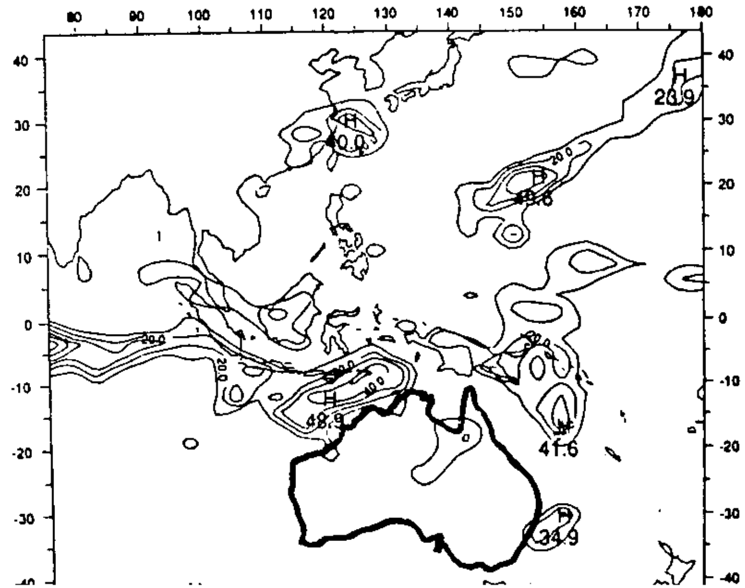
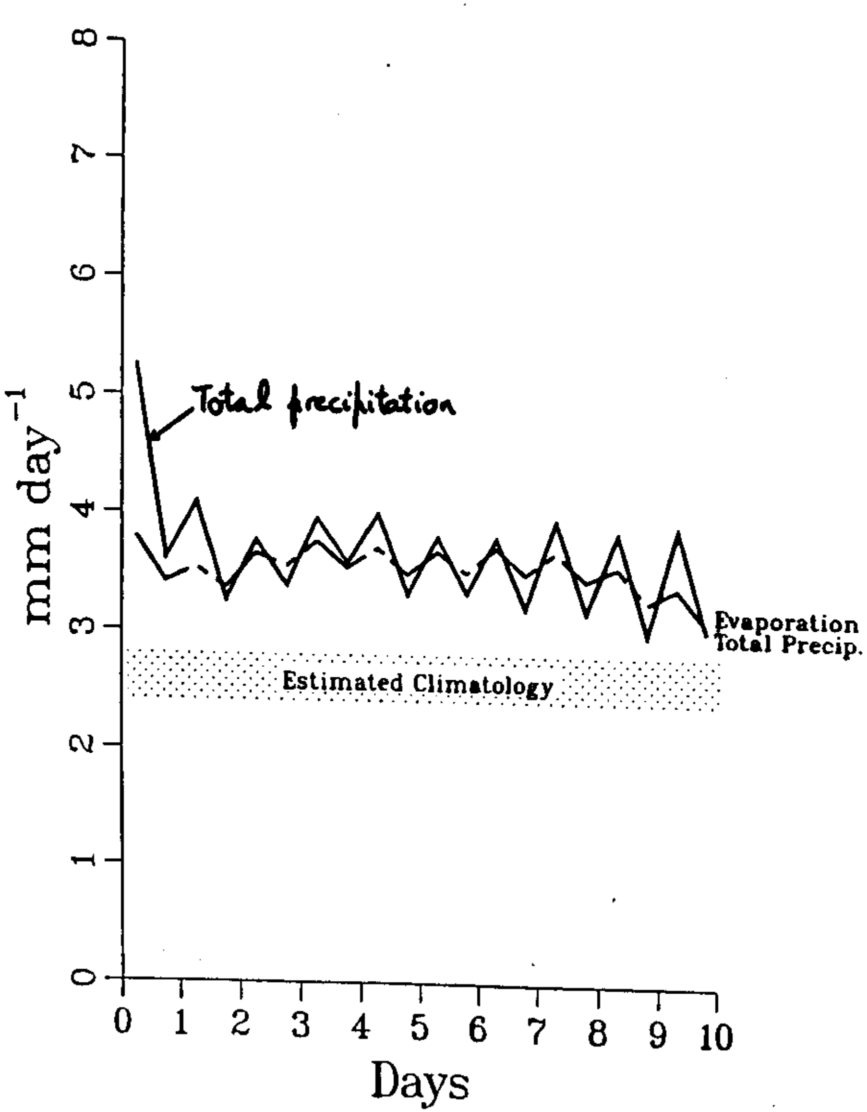
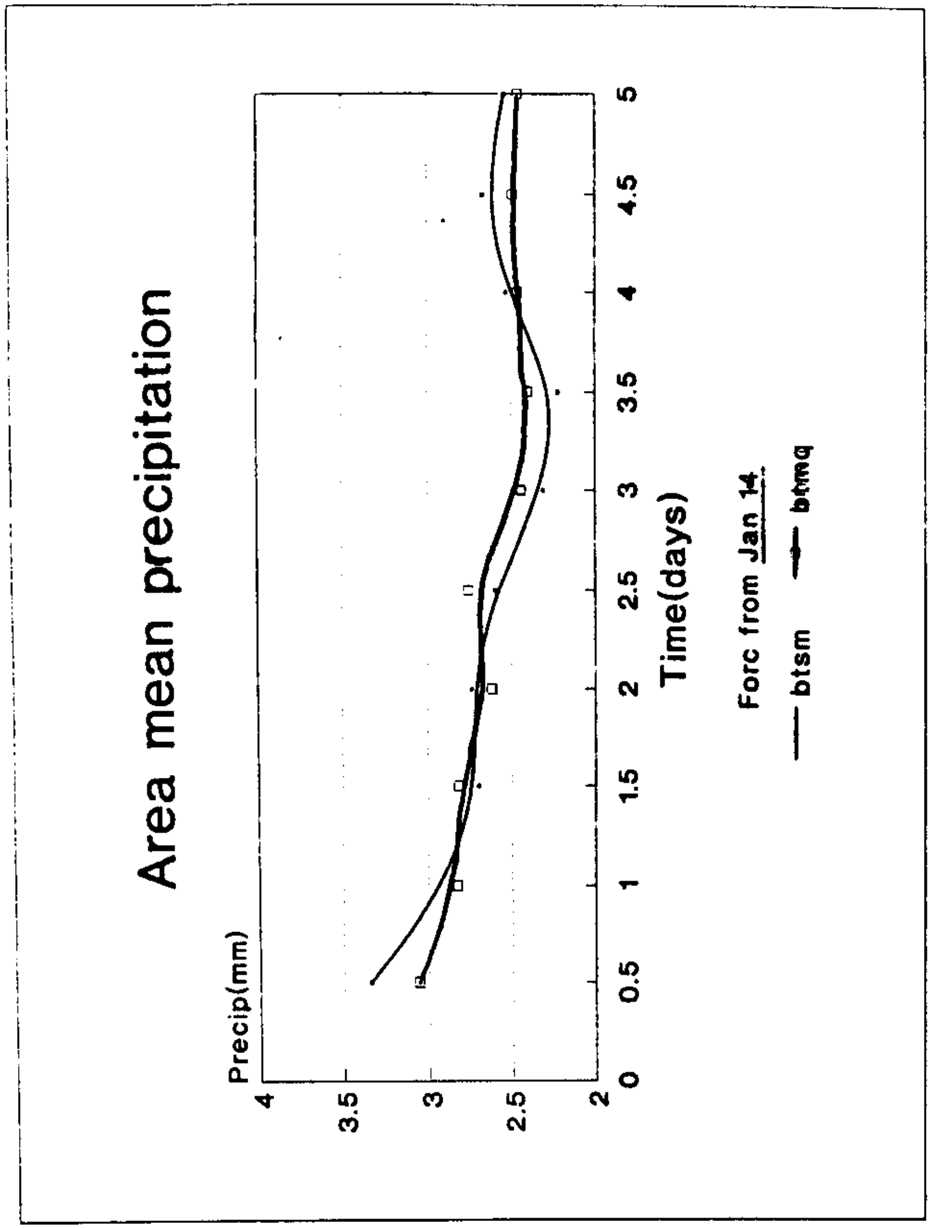
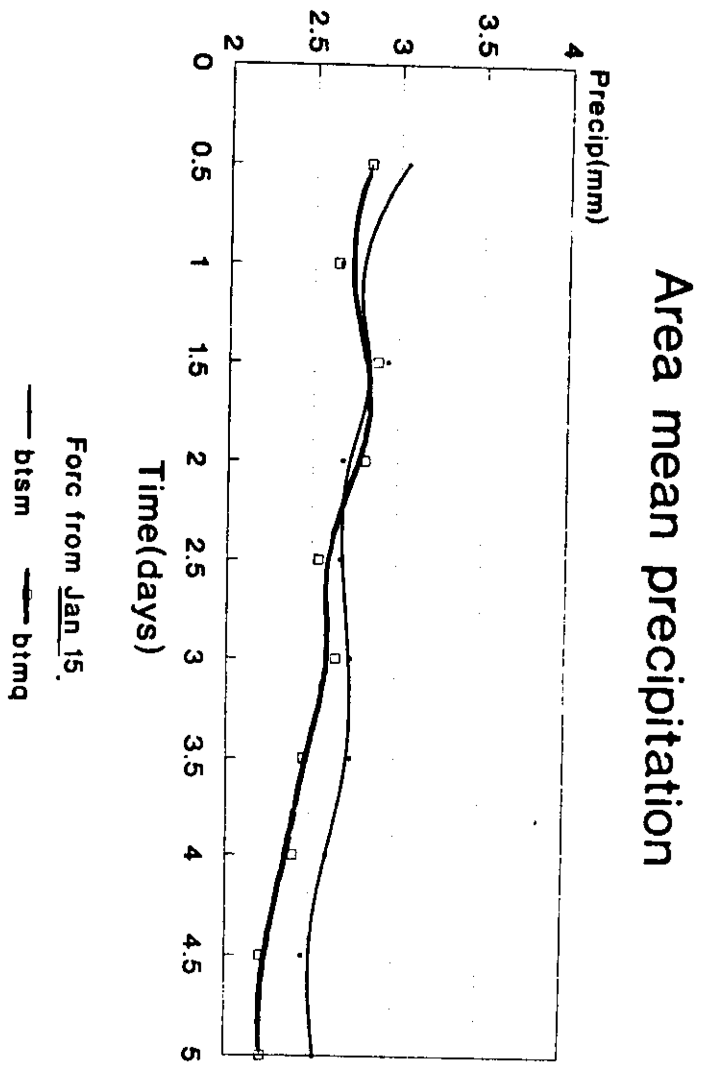


B-M + Madj

Spin up in the Betts-Miller scheme







Conclusions

- The use of bogus moisture data has a positive impact on model precipitation in the tropics.
- The use of bogus moisture data and satellite based diabatic heating eliminates spin-up in the two forcasts considered.
- Moisture initialization has a small positive impact on model spin-up and precipitation patterns.
  - However some problems with the technique need to be sorted out.

Future work

- Refine moisture initialization scheme.
- The procedures described in this talk rely on a knowledge of precipitation rates
- Data assimulation centres should consider analysing precipitation routinely using model first-guess plus all all rain gauge date,
  satellite estimated precipitation and improved retrieval techniques for SSMI data.
  - Note that GEWEX has already proposed an intercomparison study of satellite estimated precipitation

Nudging a Tropical Model With Satellite-Defined Convective Heat Sources and a Cyclone Bogus

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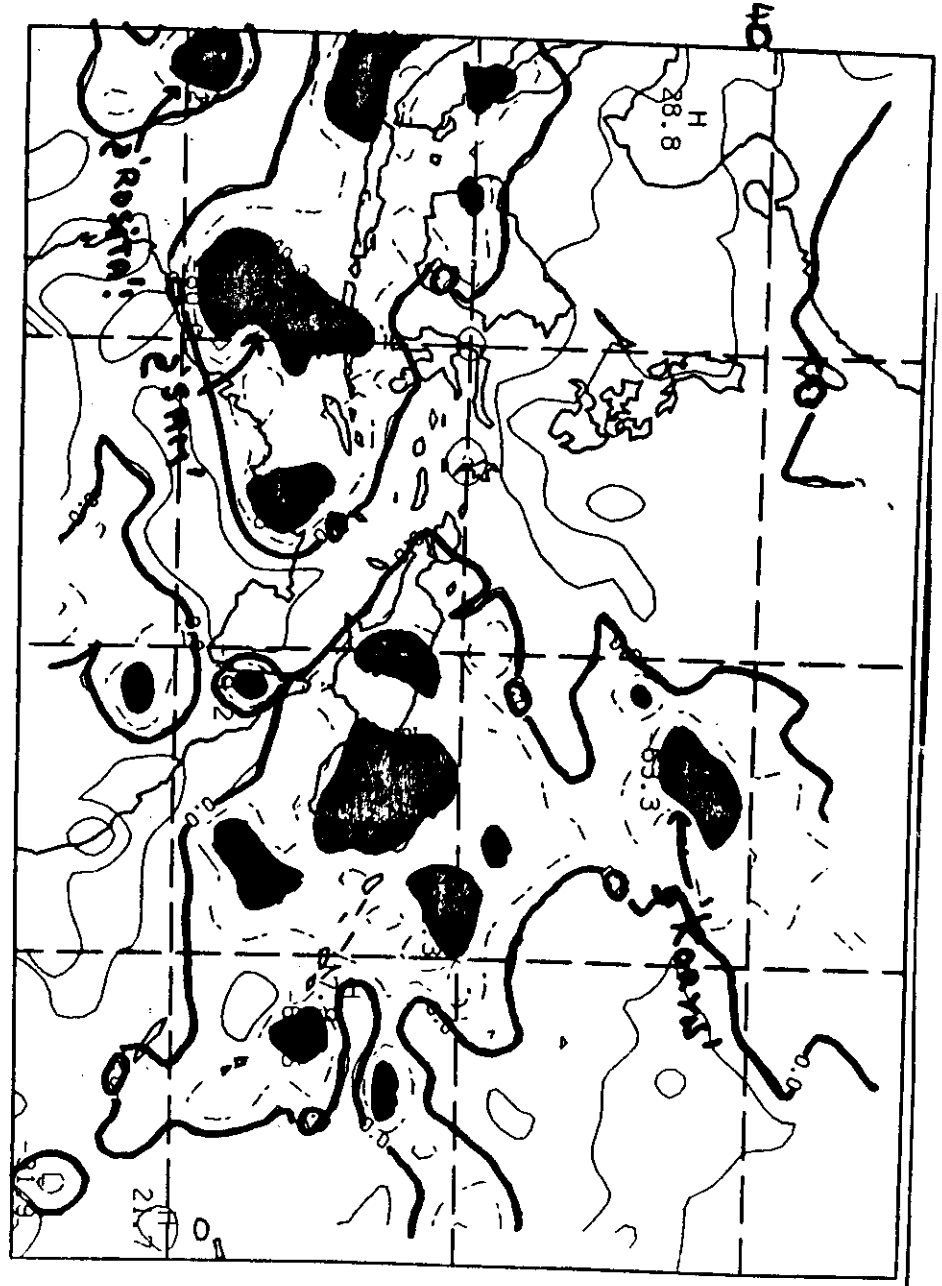
Bureau of Meterology Research Centre
Melbourne,Australia

NUDGING A TROPICAL MODEL WITH SATELLITE-DEFINED CONVECTIVE HEAT SOURCES AND A CYCLONE BOGUS

```
t=-24                                t=0
 +->--+->--+->--+->--+>>---------------+
 >>nudge model towards        ^ >>>>> forecast
   target analysis (t=0)      ^
                              ^
                      target analysis
```

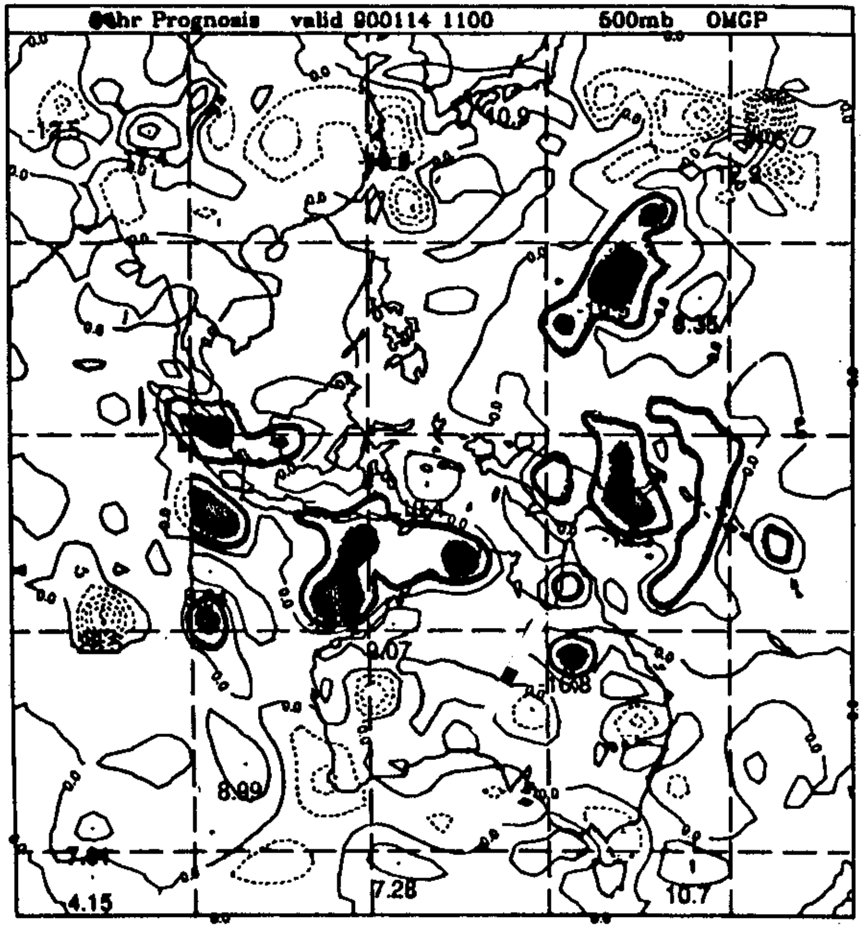
>>target analysis : re-analysis of all data + TC bogus + GMS moisture data; first guess from global 4-D assimilation system

- >>nudge to preserve the observationally-reliable rotational wind component in the target analysis
- >>replace kuo heating during nudging with satellite-defined heat sources ,updated every 3 hours (forces divergent wind component)
- >>perceived advantages
  spins model up , forces convective heating in the right place at t=0 , reduces initial position errors for TC's , improves mass-wind balance (and retention of bogus information)



TROP HCLD 900114 830

500mb ω AFTER
TC BOGUS/NUDGING/CVHEAT



500mb ω AFTER
VMI ON TARGET ANALYSIS