3-dimensional test problems for global atmospheric models

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Plan of talk

- Why?
- How?
- What?

Idealised configurations

- 1-d vertical
- 2-d horizontal - global shallow water
- 2-d slice - limited area 1-d horizontal and 1-d vertical
- 3-d limited area - with/without Earth’s rotation, with/without physics, dry/wet - approaching LES, CRM
- 3-d global dynamical core - simplified physics
- 3-d global idealised - with/without Earth’s rotation
- Aquaplanet - 3-d global, full physics, no land

Issues addressed using idealised tests

- Numerical convergence
- Coding errors
- Formulation, algorithm changes
- Accuracy - parameter sensitivity, conservation and positivity
- Efficiency
- Stability
- Grids and domains
- Boundary conditions - upper, lower and lateral
- Simplified ‘physics’ - wave propagation, energy transfers, balance, orographic effects, etc.

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Issues addressed using idealised tests

- Education
- Training
- Fun

Balanced flows

- Potential temperature

$$\frac{1}{\theta}\frac{\partial \theta}{\partial z} = \frac{N^2}{g}$$

- Hydrostatic equation

$$c_p \theta \frac{\partial \Pi}{\partial z} = -g$$

$$\Pi = \left(1 - \frac{G}{T_o}\right) + \frac{G}{T_o}\exp\left(-\frac{N^2 z}{g}\right)$$

$$G \equiv g^2 / N^2 c_p$$

Balanced flows

Geostrophic balance

$$\frac{c_p\theta}{a\cos\phi}\frac{\partial\Pi}{\partial\lambda}=2\Omega\sin\phi\,v+\frac{uv}{a}\tan\phi$$

$$\frac{c_p\theta}{a}\frac{\partial\Pi}{\partial\phi}=-2\Omega\sin\phi\,u-\frac{u^2}{a}\tan\phi$$

$$\Pi=\left(1-\frac{G}{T_o}\right)+\frac{G}{T_o}\exp\left\{-\frac{N^2}{g}\left[z+\frac{F(\phi)}{g}\right]\right\}$$

Balanced flows

$$F(\phi) \quad satisfies \quad \frac{\partial F}{\partial \phi} = au2\Omega\cos\phi + u^2 \tan\phi$$

$$\text{Choose u=u}_0\left(\frac{\cos^n\phi - \cos^n\phi_X}{\cos^n\phi_M - \cos^n\phi_X}\right)$$

$$\text{n = 1 or 2 ,} \quad \phi_{\text{M}} \text{ axis of jet,} \quad \phi_{\text{X}} \text{ limit of jet}$$

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Balanced flows

n = 1 , ϕ_{M} axis of jet, ϕ_{X} limit of jet

$$F(\phi) = \frac{a2\Omega u_o \cos\phi}{D}\left(X - \frac{\cos\phi}{2}\right)$$

$$-\frac{u_o^{\,2}}{D^2}\left[\frac{\cos^2\phi}{2} - 2X\cos\phi + X^2\ln\left|\cos\phi\right|\right]$$

$\mathrm{X}=\cos\phi_{\mathrm{X}}$ $\qquad$ $\mathrm{D}=\mathrm{M}-X$

Match constants of integration

Balanced flows

$\mathrm{n} = 2\,,\quad \phi_{\mathrm{M}}$ axis of jet, ϕ_{X} limit of jet

$$F(\phi) = \frac{a2\Omega u_o \cos\phi}{D}\left(X^2 - \frac{\cos^2\phi}{3}\right)$$

$$-\frac{u_o^{\,2}}{D^2}\left[\frac{\cos^4\phi}{4} - X^2\cos^2\phi + X^4 \ln\left|\cos\phi\right|\right]$$

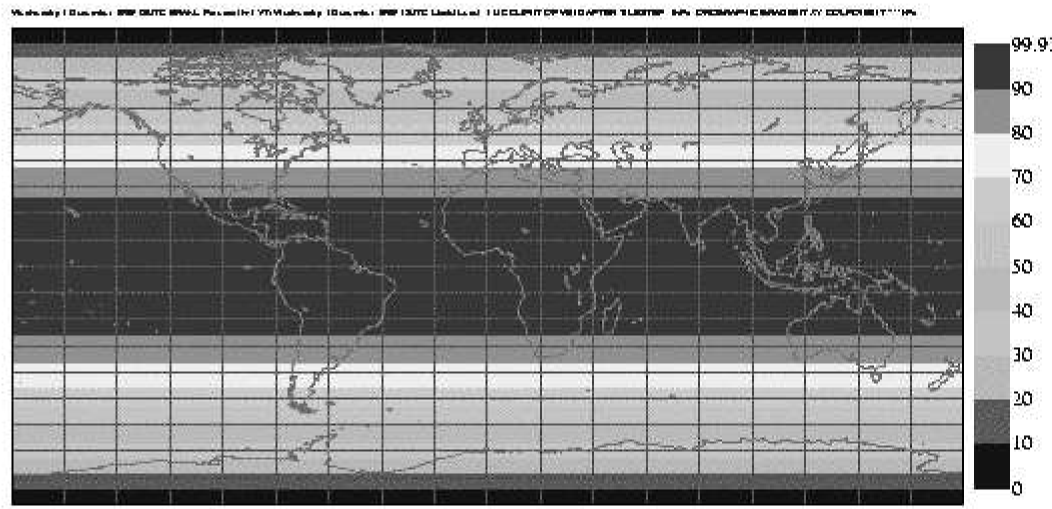
$\mathrm{X} = \cos\phi_{\mathrm{X}} \qquad \mathrm{D} = \mathrm{M}^2 - X^2$

Match constants of integration

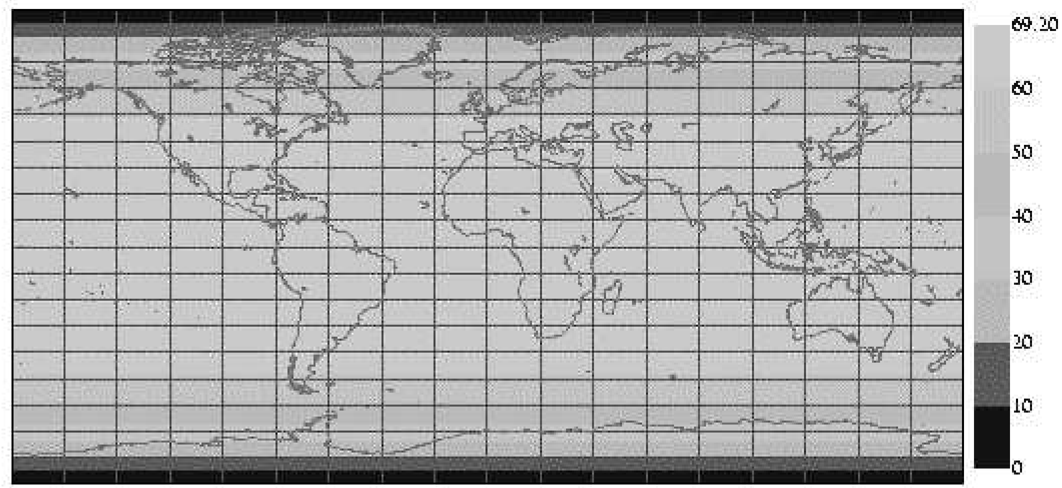
N48L40
96x73

$Dt = 30\,\mathrm{min}\,s$

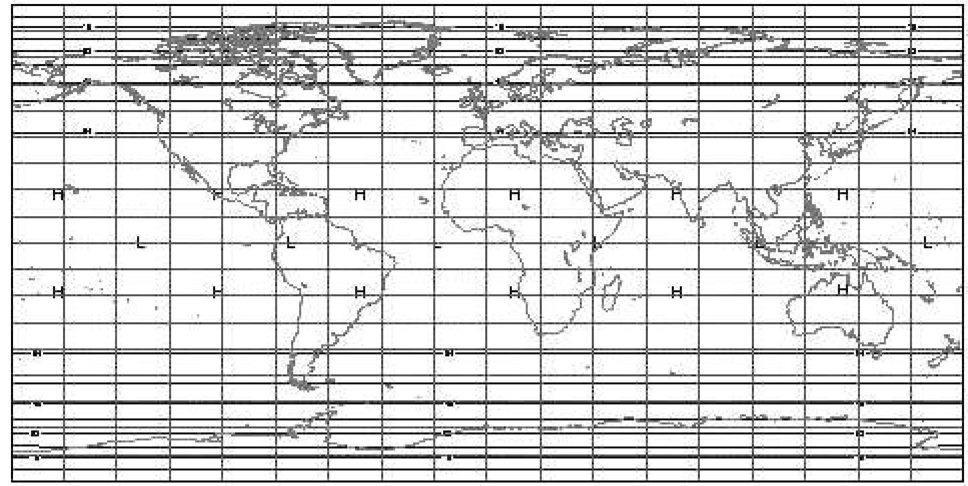
Zonal wind
1 day



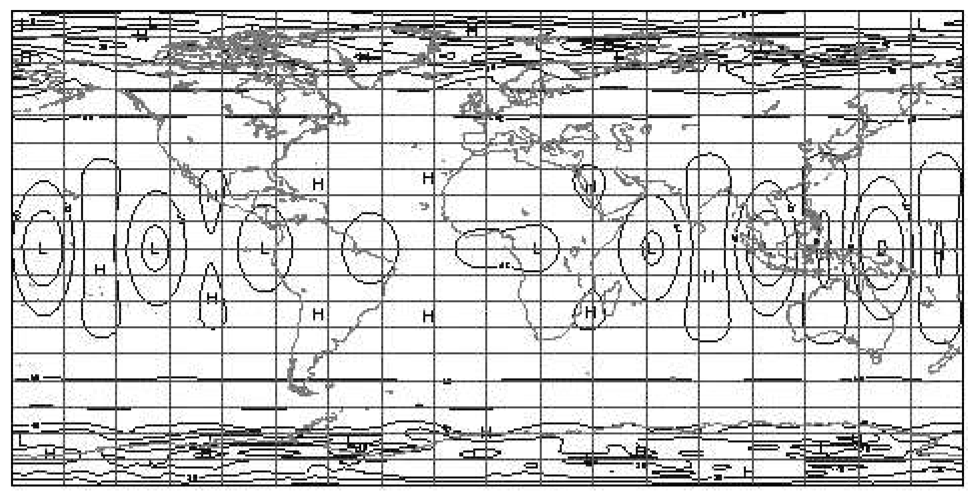
Zonal wind
30 days



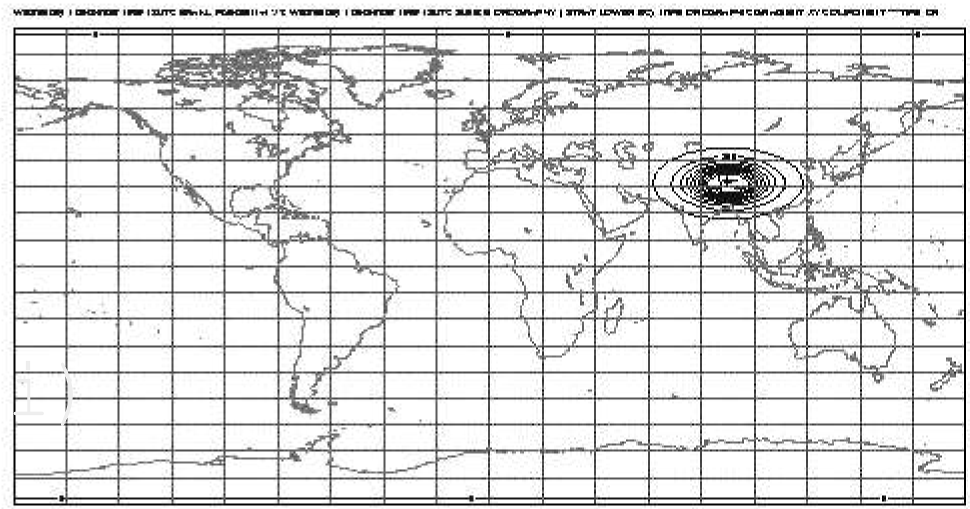
Zonal wind
30 days
Implicit weight
0.6

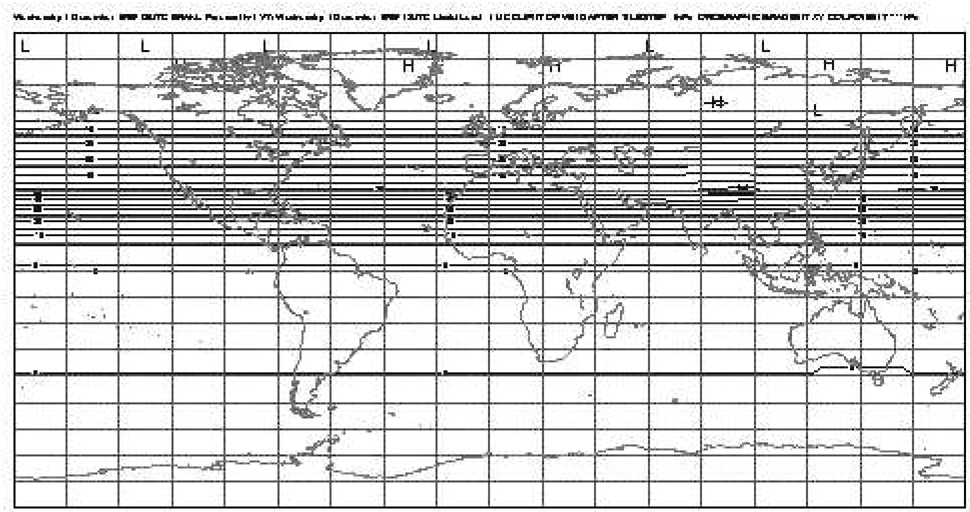


Zonal wind
30 days
Implicit weight
0.55



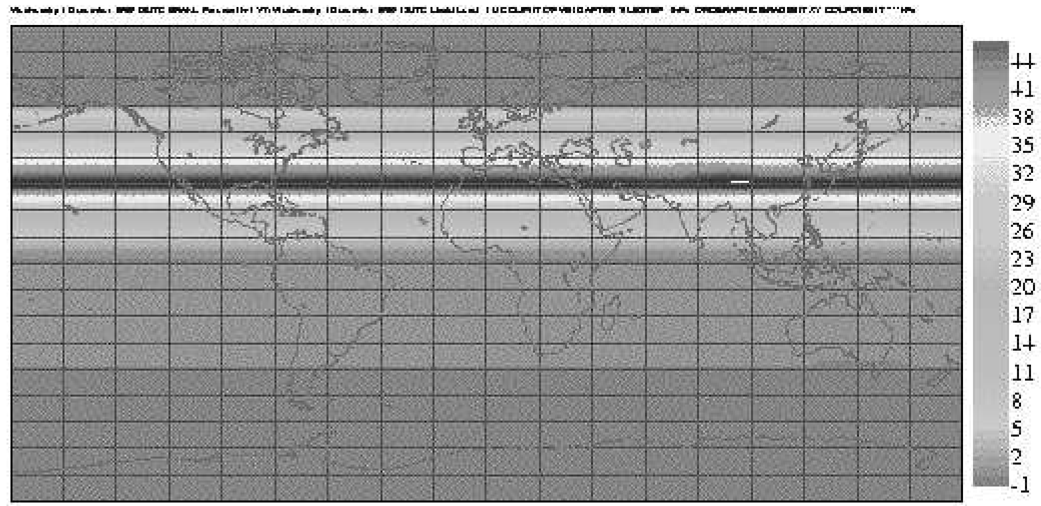
Idealised orography
1000m plateau
(Beheaded
Witch of Agnesi)



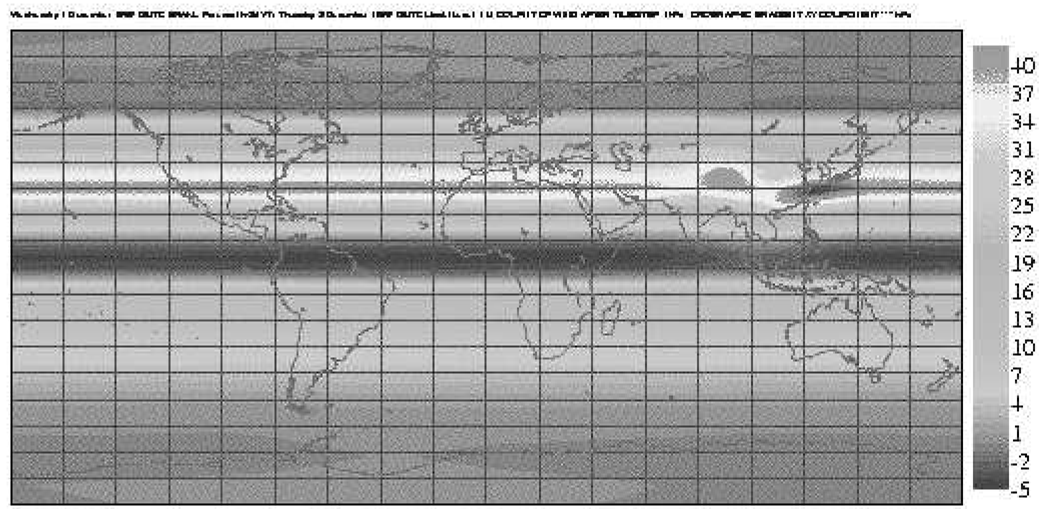


Initial flow
50m/s jet
cosine squared

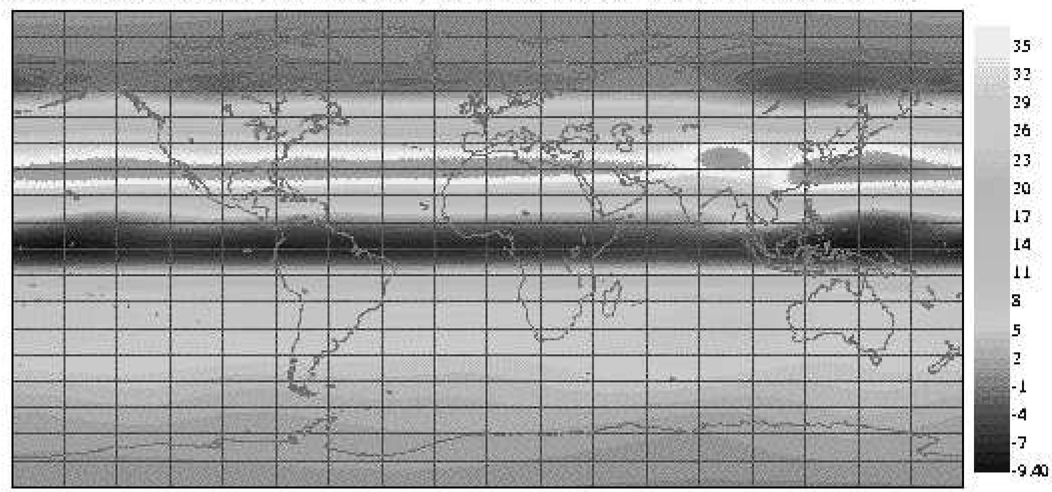
Initial flow



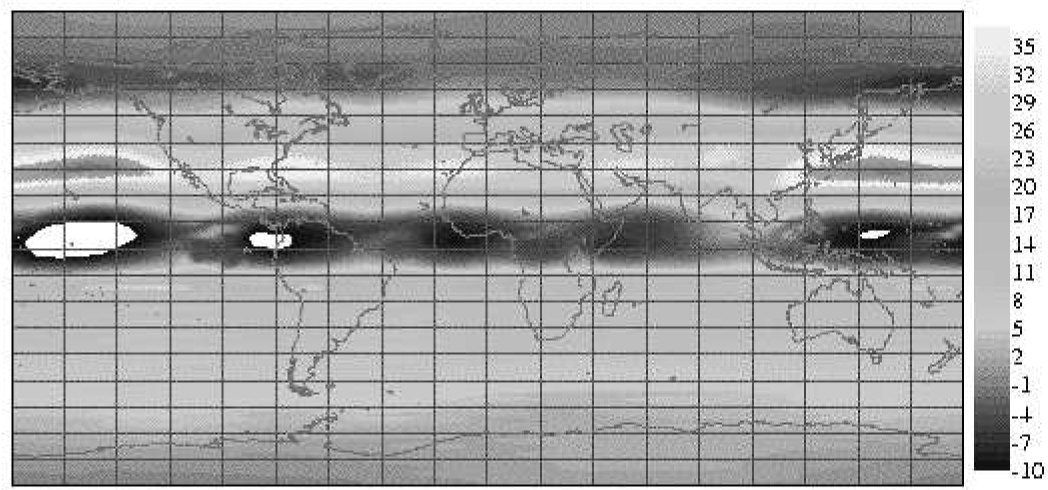
Zonal wind T+24



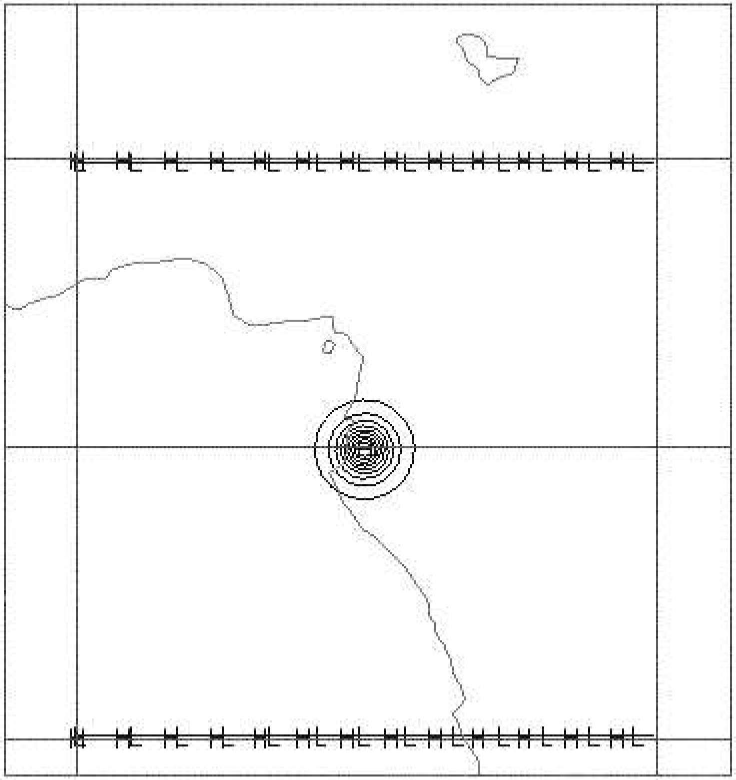
Zonal wind
10 days



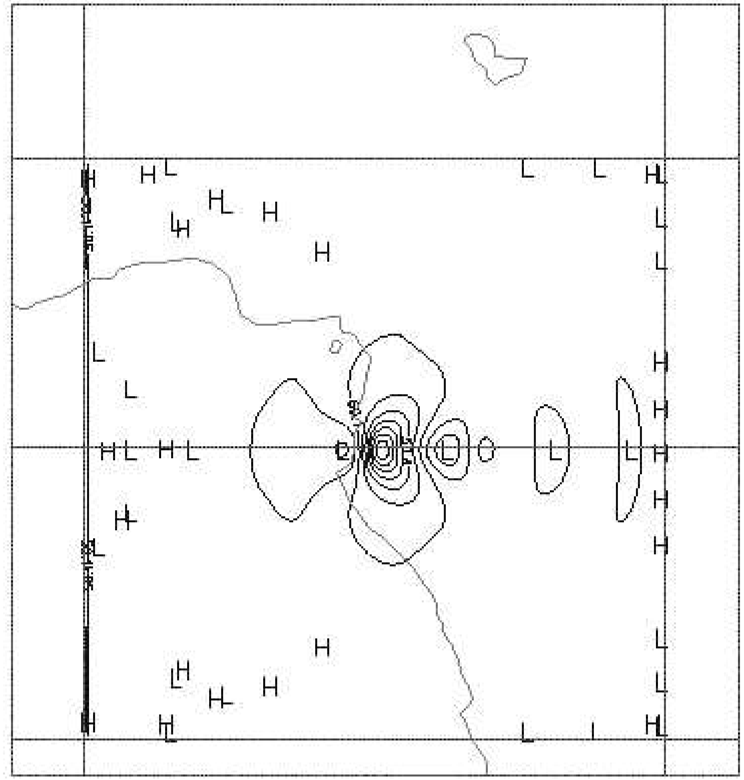
Zonal wind
30 days



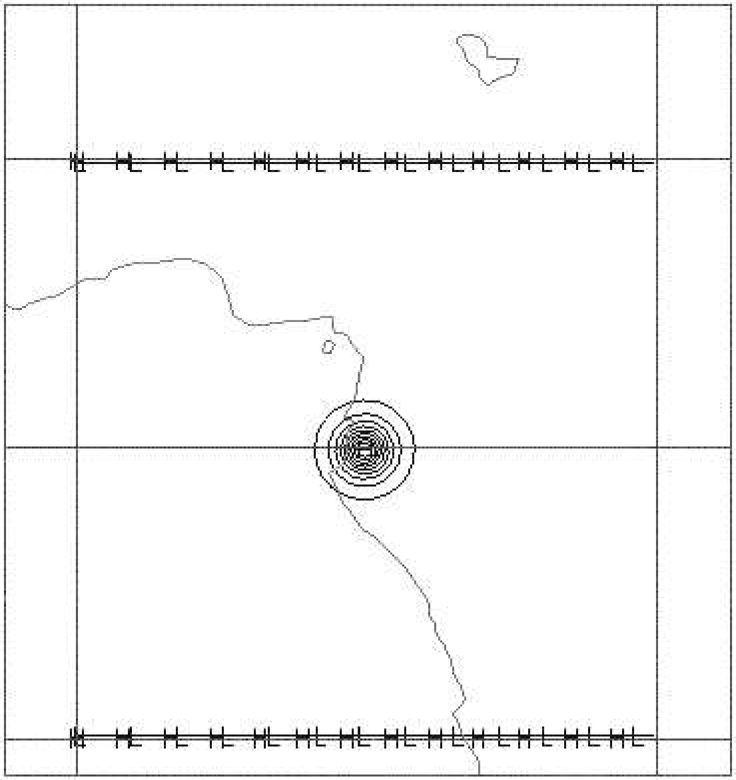
sfc 33 2000-01-15 12h fc t+7 vt:2000-01-15 19h



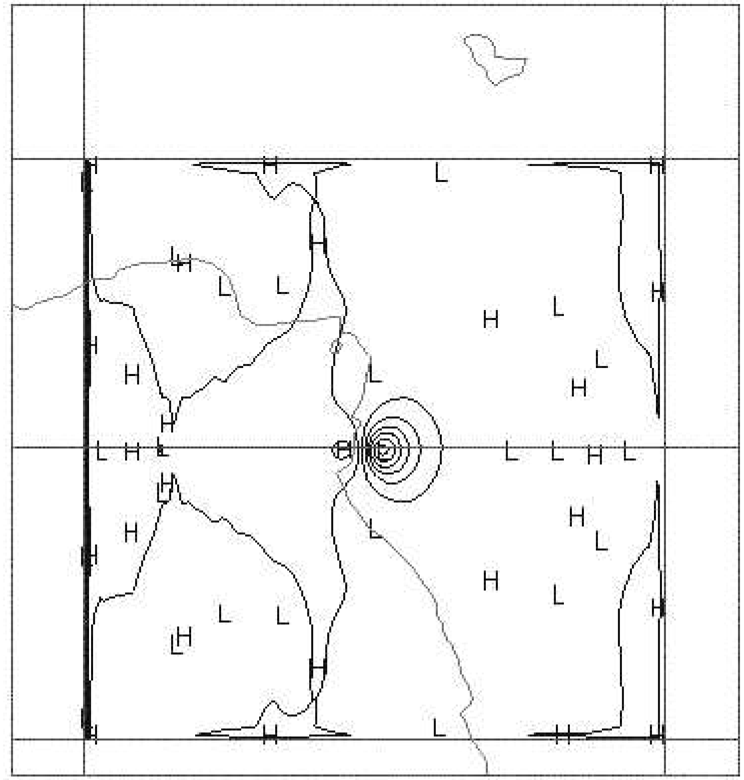
850hPa U 2000-01-15 12h fc t+8 vt:2000-01-15 20h



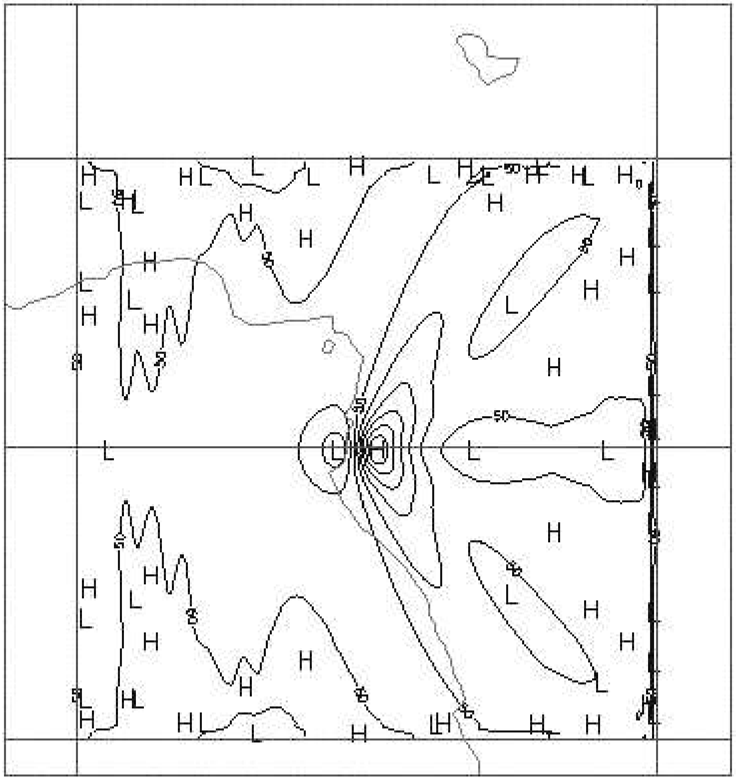
sfc 33 2000-01-15 12h fc t+7 vt:2000-01-15 19h

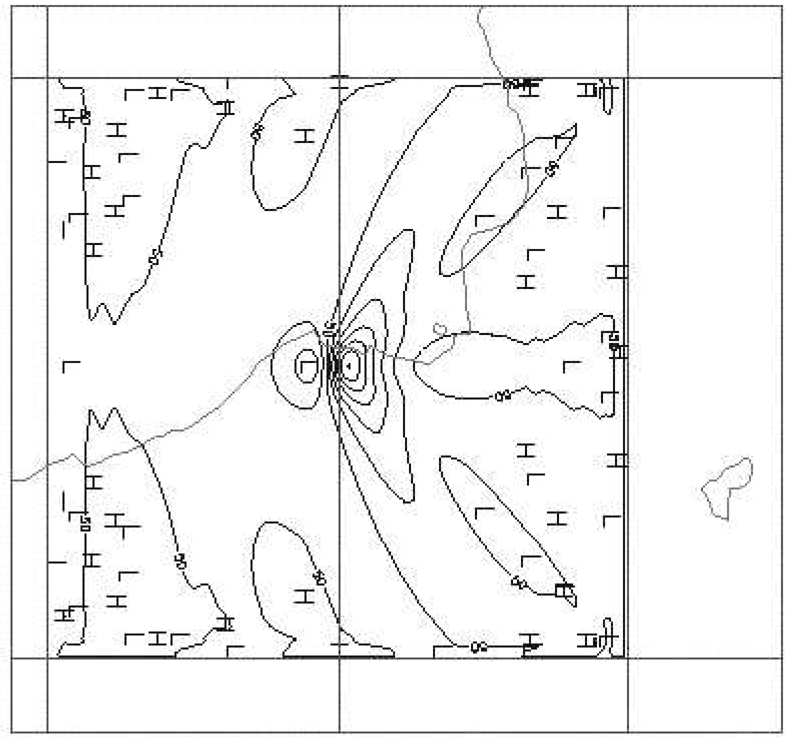


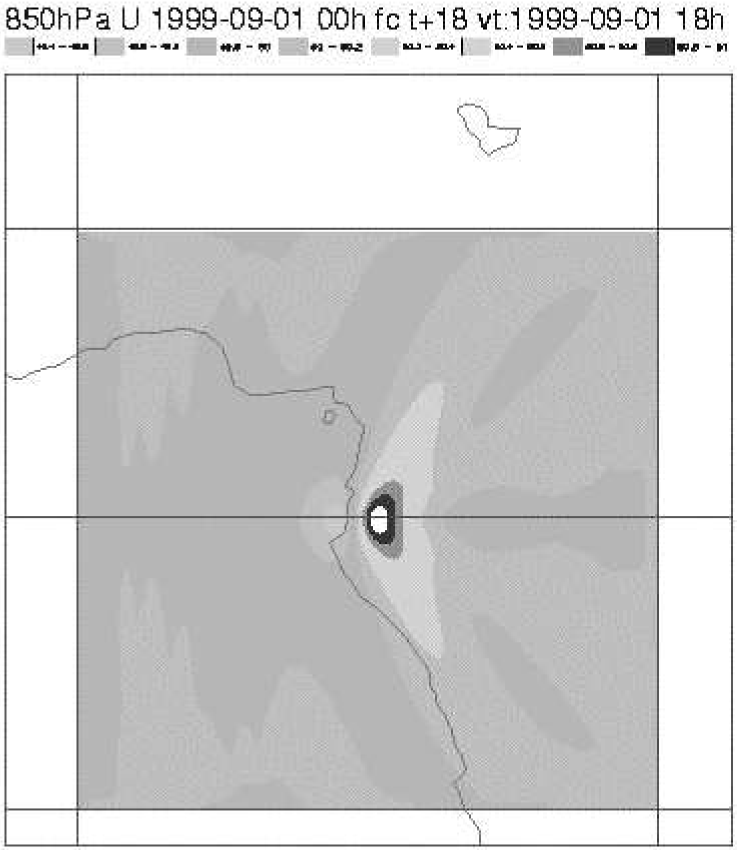
msl pmsl 2000-01-15 12h fc t+8 vt:2000-01-15 20h

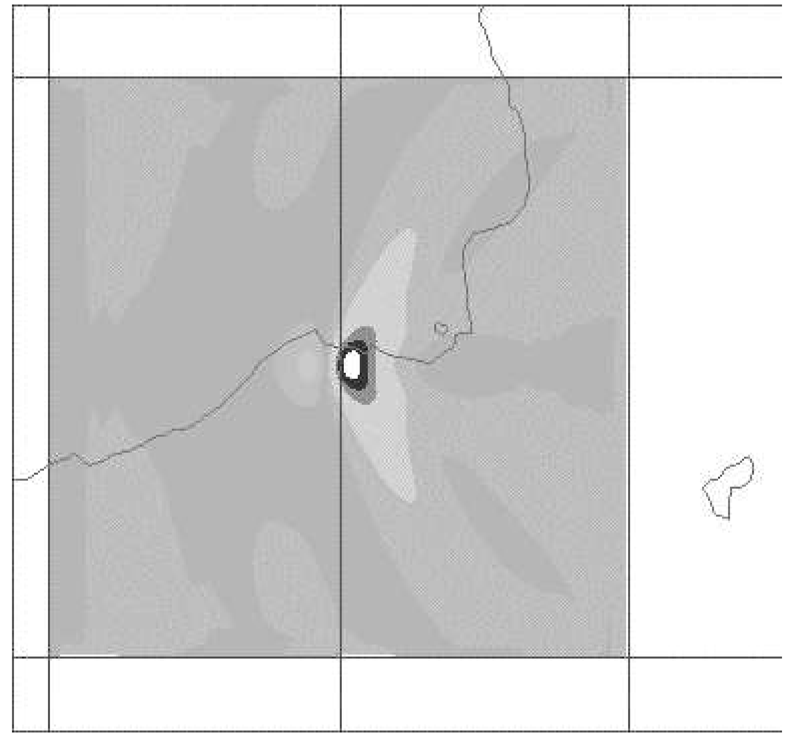


850hPa U 1999-09-01 00h fc t+18 vt:1999-09-01 18h

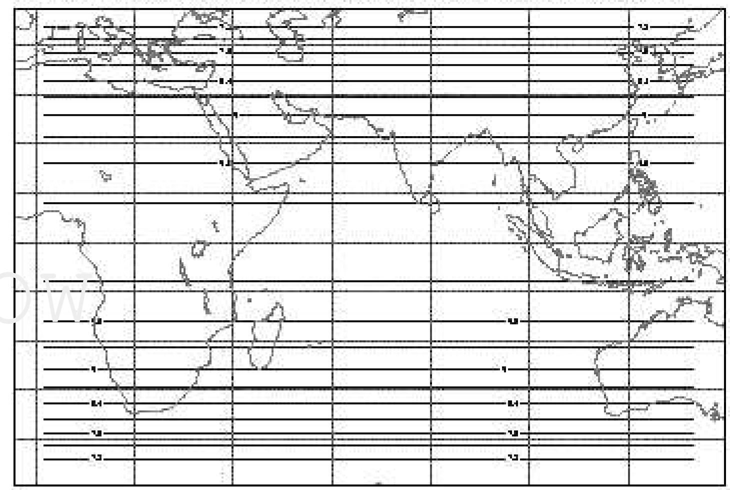




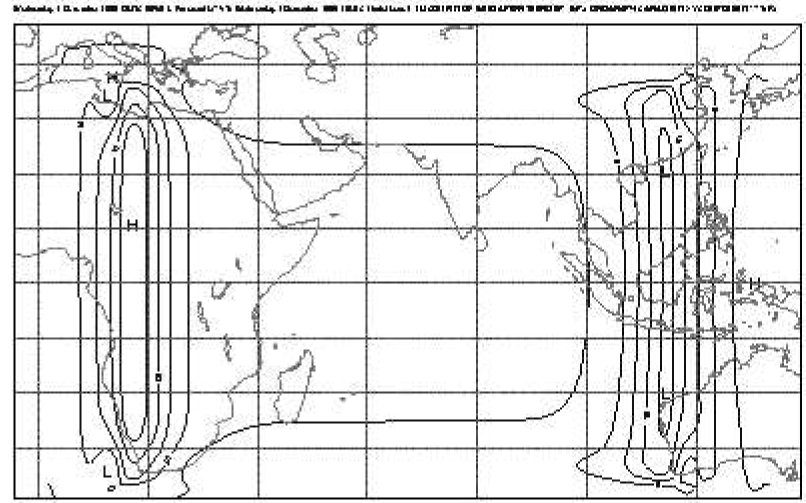

850hPa U 1999-09-01 00h fc t+18 vt:1999-09-01 18h



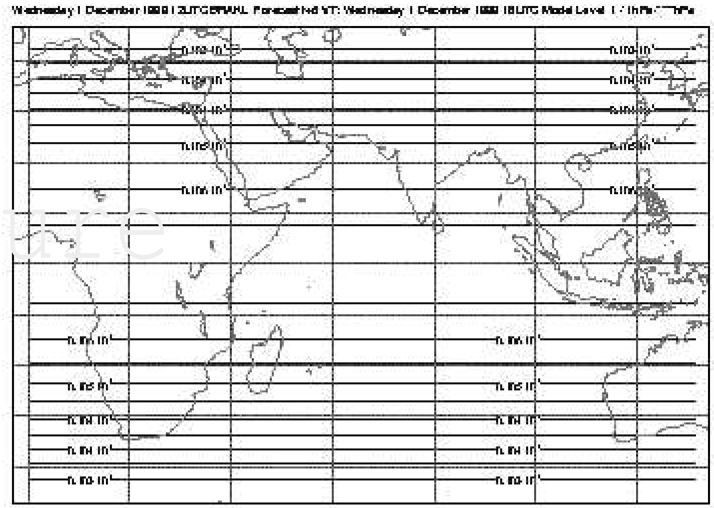
Initial flow
T+0



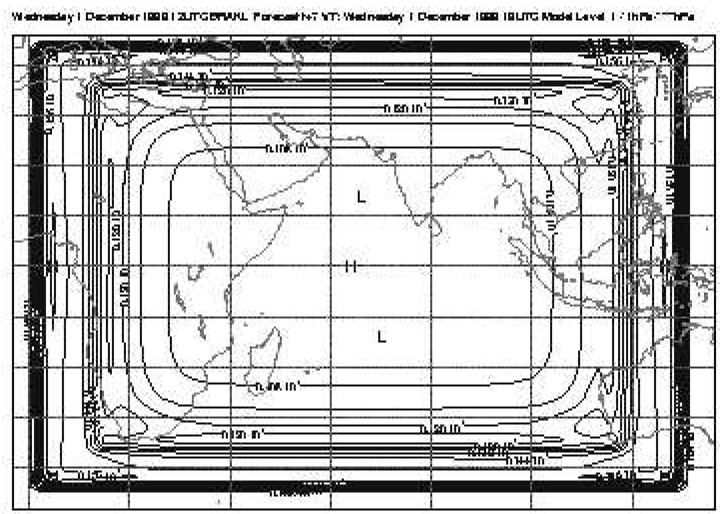
1 hour
forecast



Initial pressure T+0



1 hour forecast



Conclusions

- 3-d balanced flow suitable for idealised testing of atmospheric global models.
- Can position zonal jet where desired.
- Also useful for testing nesting strategies for limited area models.
- Questions?