“Convection Resolving Model” (CRM)
MOLOCH

1-Breve descrizione del CRM sviluppato all’ISAC-CNR

2-Ipotesi alla base della parametrizzazione dei processi microfisici

National Research Council

Objectives

• Develop a tool for very high resolution-short range operational weather forecast and Nowcasting;

• 'Resolve' explicitly atmospheric convection (without parameterization);

• Develop a tool for research purposes (simulation of thunderstorm development, flows over complex orography, physical processes responsible for intense precipitation, ……

Model dynamics

• non hydrostatic, fully compressible;

• Arakawa C grid; terrain-following coordinate

• time split, implicit for vertically propagating sound waves, FB for horizontal prop. waves

• advection: FBAS (Malguzzi & Tartaglione, 1999); also Weighted Average Flux WAF (Toro 1989; Hubbard & Nikiforakis, 2001)

• nested in BOLAM runs

Model physics

• radiation, vertical diffusion, surface turbulent fluxes similar to BOLAM

• soil water and energy balance based on Pressman soil scheme

• cloud microphysics (partly based on Drofa, 2003)

• no dry and moist convection

Governing equations

$$\frac{du}{dt} = -\frac{1}{\rho}\frac{\partial P}{\partial x} - fv + K_u$$

$$\frac{dv}{dt} = -\frac{1}{\rho}\frac{\partial P}{\partial y} + fu + K_v$$

$$\frac{dw}{dt} = -\frac{1}{\rho}\frac{\partial P}{\partial z} - g$$

$$\frac{dT}{dt} = -T\,\frac{R'}{C_V}\,\vec{\nabla}\cdot\vec{V} + \frac{\dot{Q}}{C_V} + K_T$$

$$\frac{dP}{dt} = -P\,\gamma\,\vec{\nabla}\cdot\vec{V} + \frac{P\dot{Q}}{C_V T}$$

$$P = \rho\, R'\, T$$

Effective gas constant

$$R' = R_d\left(1 + \left(1/\varepsilon - 1\right) q_V - q_W - q_I\right)$$

$$\gamma = \frac{C_P}{C_V} \qquad \varepsilon = \frac{R_d}{R_V}$$

Governing equations:
Conservation of specific concentration of water species in air parcels

$$\frac{dq_k}{dt} = \delta_{kV} K_V + \ldots\ldots\ldots\ldots\ldots$$

$$k = V\,,\;\; Cw\,,\;\; Ci\,,\;\; Pw\,,\;\; Pi_1\,,\;\; Pi_2$$

Hydrometeors

Turbulent kinetic energy equation in H-coordinates

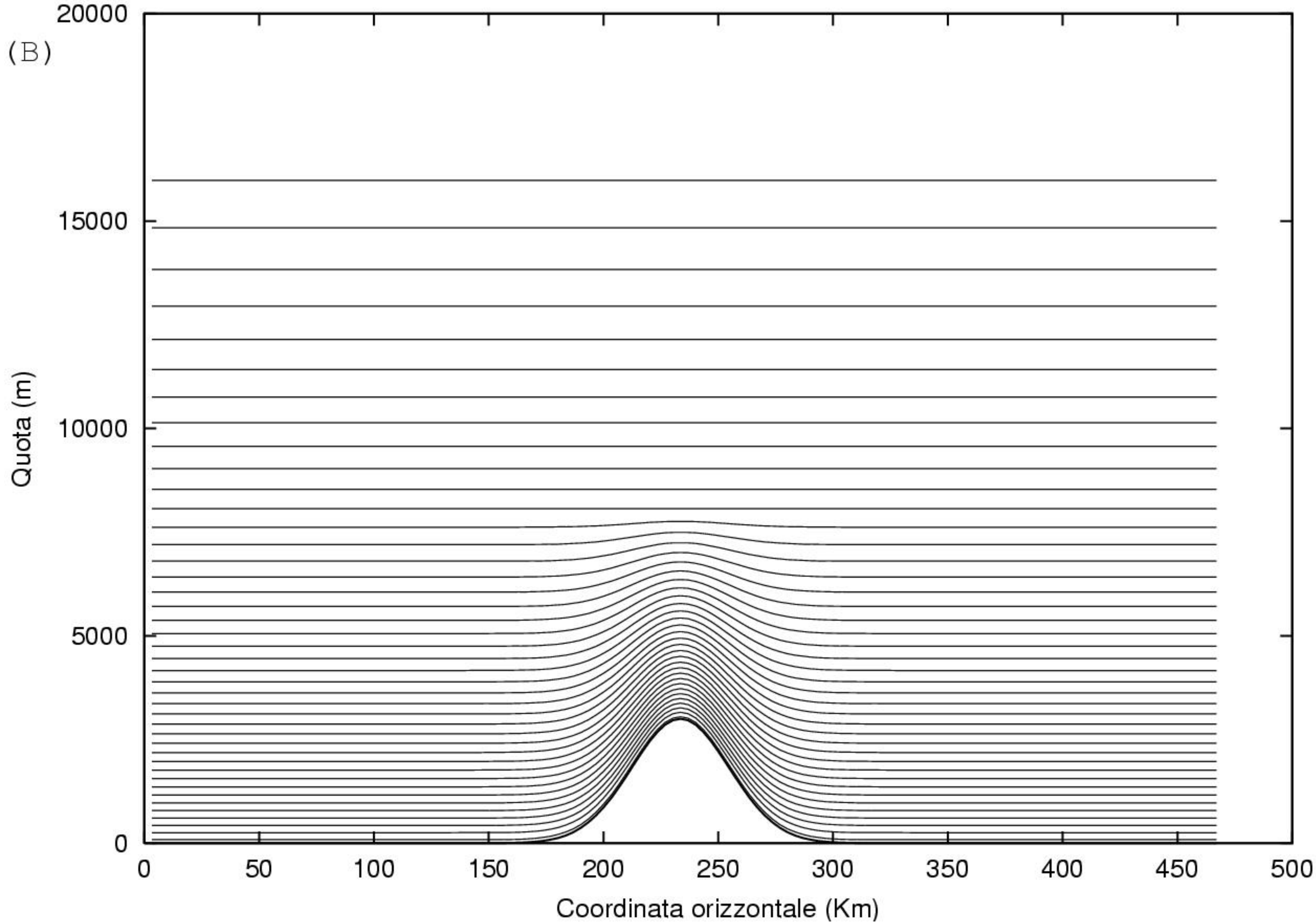
$$\frac{d\bar{E}}{dt} = K_E - \overline{u_i' u_j^{¿}{}'}\,\frac{\partial \bar{u}_i}{\partial x_j}\Big|_{\varsigma} + \frac{g}{\bar{\theta}_V}\,\overline{w'\theta'_V} - \varepsilon, \quad \vec{u}' = \begin{pmatrix} u' \\ v' \\ w' \end{pmatrix}, \quad \vec{u}^{¿}{}' = \begin{pmatrix} u' \\ v' \\ s' \end{pmatrix}$$

$$\bar{E} = \frac{1}{2}\left(\overline{u'u'} + \overline{v'v'} + \overline{w'w'}\right) \qquad \varepsilon = \frac{1}{l_m}\left(\sqrt{C_E \bar{E}}\right)^3$$

Closure: Energy redistribution hypothesis

$$\overline{u_i' u_j'} = \frac{2}{3}\delta_{ij} E - K\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) \qquad K = l_m \sqrt{C_E E}$$

Hybrid coordinates ‘*H*’



H-Coordinate

Terrain following vertical coordinate

$$\zeta = H\left(1 - e^{-\frac{z - h(1-\zeta/H)}{H}}\right)$$

$$h < z < \infty$$

The vertical scale H is given by the *density scale height*

$$H = \frac{R_d T_0}{g}$$

Microphysical hypothesis

Liquid and solid cloud particles: gamma-distribution (Levi distribution) for the number of particles per unit volume and unit radius D:

$$N(D) = \frac{N_0 \beta^{\alpha+1}}{\Gamma(\alpha+1)} D^{\alpha} e^{-\beta D}$$

$N_0 = 8 \cdot 10^6$ (m^{-3}) and $\alpha = 6$ for cloud drops

$N_0 = 2 \cdot 10^7$ (m^{-3}) and $\alpha = 3$ for cloud crystal

Liquid and solid precipitation: Marshall-Palmer distribution

$$N(D) = N_0 e^{-\lambda D}$$

$N_0 = 8 \cdot 10^6$ (m^{-4}) for precipitating drops

N_0 function of crystal shape for precipitating ice

β *and* λ are determined from the normalizing condition: $$\frac{1}{\rho} \int N(D) m(D) \, dD = q$$

where m is the mass of a particle of diameter D: $$m(D) = aD^b$$

and where $a = \pi/6 \cdot \rho_w$, $b = 3$ for cloud and precipitating water; $a = 100$, $b = 2.5$ for cloud ice; a and b function of crystal shape (temperature) for precipitating ice. The result is:

$$\beta = \left[\frac{N_0 a \Gamma(\alpha+b+1)}{\rho q \Gamma(\alpha+1)} \right]^{\frac{1}{b}}$$

$$\lambda = \left[\frac{N_0 a \Gamma(b+1)}{\rho q} \right]^{\frac{1}{b+1}}$$

The rate of change of the quantity q due to a particular microphysical process is given by:

$$\frac{\partial q}{\partial t} = \frac{1}{\rho} \int_0^{\infty} \frac{\partial m}{\partial t} N(D)\, dD$$

where $\frac{\partial m}{\partial t}$ is the rate of change of the mass of a single particle

Condensation-sublimation

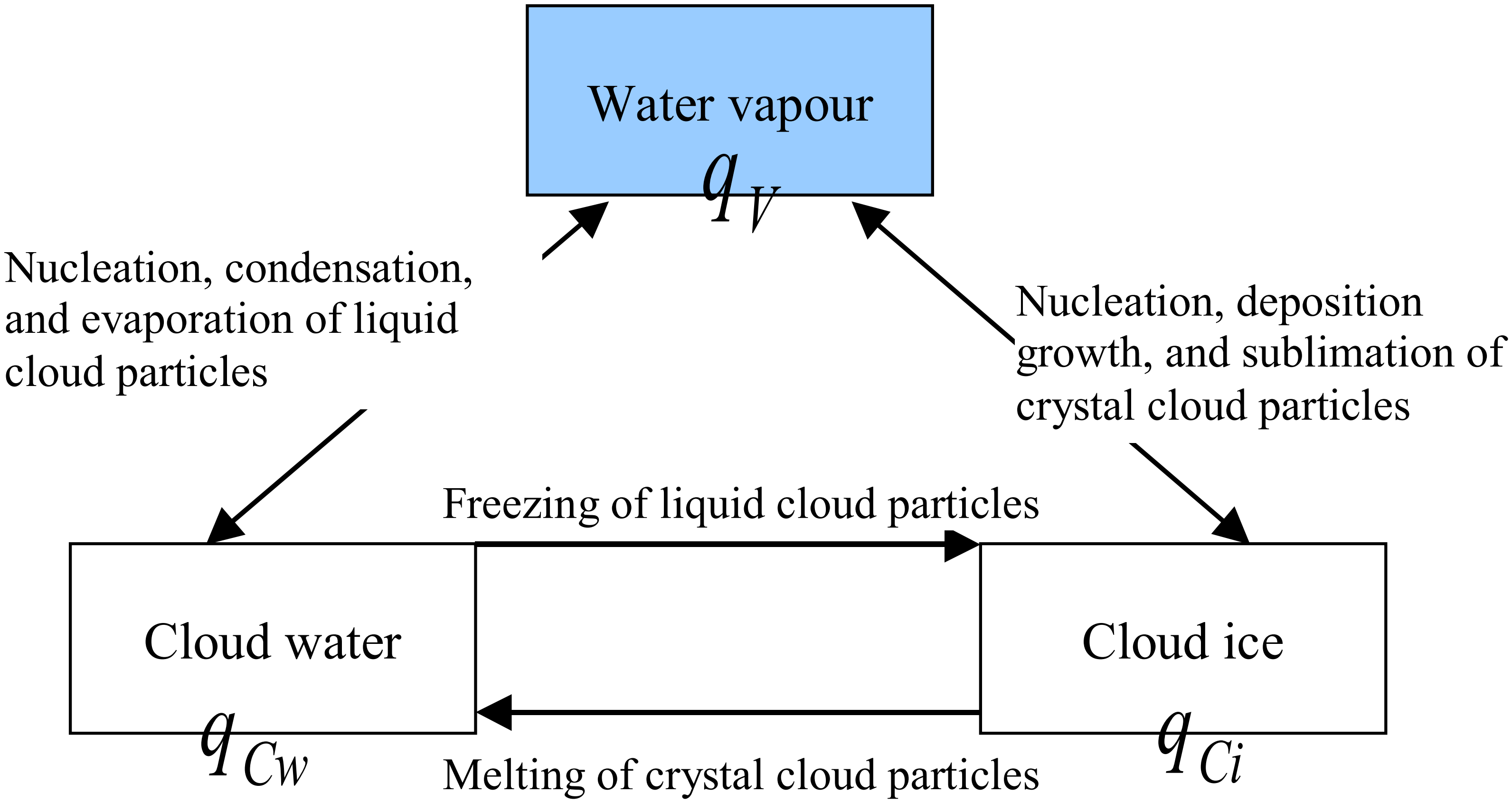
$$\frac{dm}{dt} = D \cdot \frac{2\pi\ F \left(\frac{q_v}{q_{sk}} - 1 \right) \rho}{\frac{1}{q_{sk}\chi} + \frac{L_k^v M_w}{K_a T} \left(\frac{L_k^v M_w}{R^{*} T} - 1 \right)} \cdot \left\{ 1 - \frac{1}{2} \left(\frac{q_v}{q_{sk}} - 1 \right) \left[\frac{\rho \left(\frac{L_k^v M_w}{R^{*} T} - 1 \right)}{\frac{K_a T}{q_{sk}\chi L_k^v} + \rho \left(\frac{L_k^v M_w}{R^{*} T} - 1 \right)} \right]^2 \left[1 + \frac{1 - 2 \frac{L_k^v M_w}{R^{*} T}}{\left(\frac{L_k^v M_w}{R^{*} T} - 1 \right)^2} \right] \right\}$$

where F is the ventilation coefficient, equal to 0.8 for cloud particles. For precipitation particles the following expression is implemented:

$$F = 0.78 + \mathbf{Sc}^{1/3} \left(\frac{D U \rho}{\mu_{dif}} \right)^{1/3}$$

where μ_{dif} is the dynamical molecular viscosity of air, U the terminal velocity of the particle, and Sc the Shmidt number (= 0.6). The suffix k can be w or i, indicating liquid water or ice, respectively. L_w^v and L_i^v are the condensation and sublimation latent heat, χ the coefficient of molecular diffusion of vapour into air, K_a the thermal conductivity of air, M_w the molecular weight of water, and R^* the universal gas constant.

Fast microphysical processes



‘Autoconversion’

$$\frac{\partial q_{Cw,Ci}}{\partial t} = -q_{Cw,Ci} \frac{\Gamma(\alpha + b + 1, \ \beta D_0)}{\Delta t \ \ \Gamma(\alpha + b + 1)}$$

Fall of precipitation

The terminal velocity of one precipitation particle:

$$u(D)=kD^n\left(\frac{p_0}{p}\right)^{0.4}$$

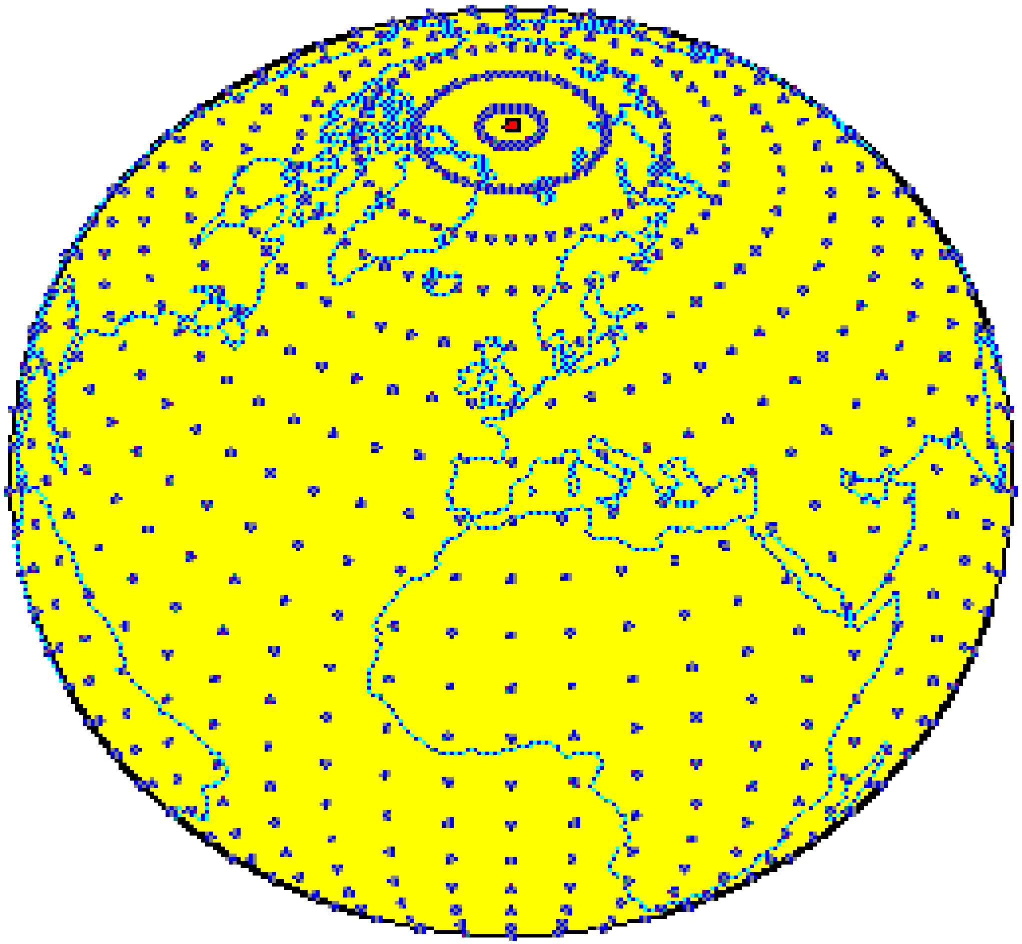
where n=0.8 and k=842 $m^{1-n}s^{-1}$ for rain and function of the type of ice particle for snow/hail

Averaged terminal velocity:

$$U=\frac{\int N(D)m(D)u(D)dD}{\int N(D)m(D)dD}$$

Conclusioni

'GLOBO'
GLObal version of the BOlam model



National Research Council

Model dynamics

- Hydrostatic, primitive equations
- Arakawa C grid; terrain-following, hybrid coordinates
- Explicit time split, Forward-Backward for gravity waves
- Advection: Weighted Average Flux (Toro 1989; Hubbard & Nikiforakis, 2001)
- Fourth order horizontal diffusion and second order divergence damping
- Polar filter (spectral along longitude)

Model physics:

- Radiation (Morcrette or Geleyn)
- Vertical diffusion (*E-l* scheme)
- Surface turbulent fluxes (Monin-Obuckov)
- Large scale precipitation and microphysics based on Shultz (1988)
- Moist convection based on the Kain-Fritsh parameterization
- Soil water and energy balance scheme based on Pressman (1994)
- Vegetation effects (Noilhan J., Mahfouf J.-F. ,1996)
- Gravity wave drag

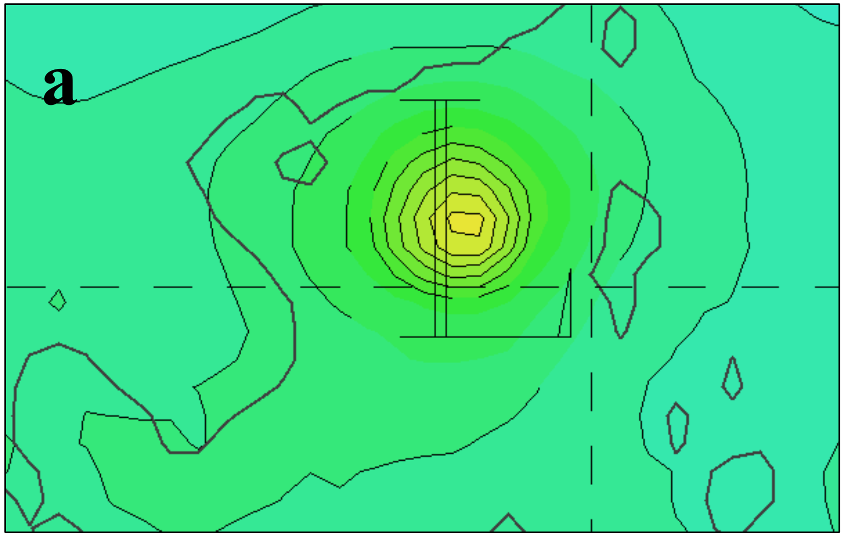
Case study : 2006/05/15

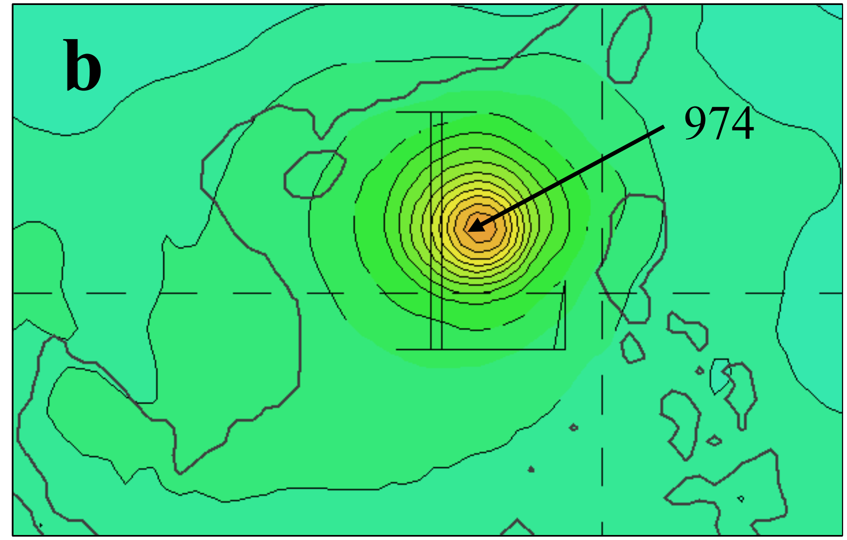
7-day forecast simulation, starting from ECMWF analysis at 00 UTC of May 15, 2006

3-D fields *u, v, T, q* extracted from *MARS* archive on 26 model levels and 1.0x1.0 lat-lon regular grid (12 Mbyte compressed).

2-D fields: soil temperature and water content (4 layers), snow height, log. of surface pressure, orography, and land sea mask.

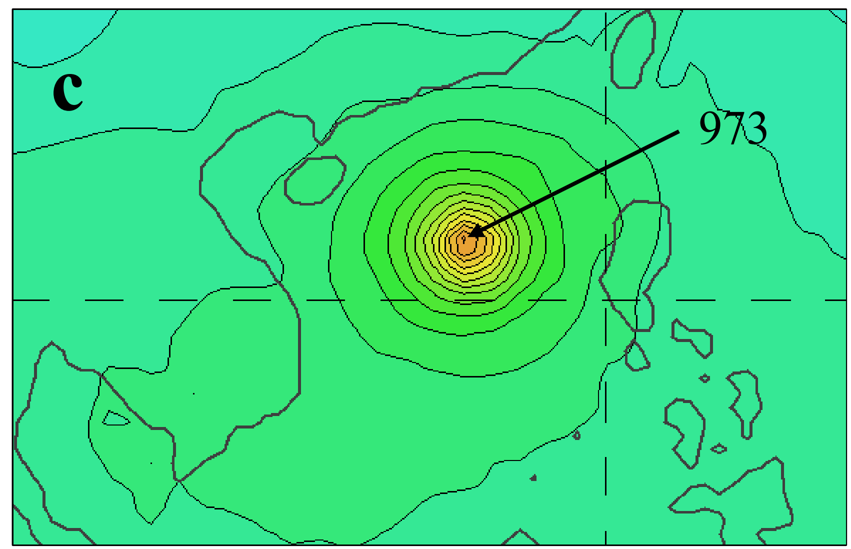
System time: 1 hour (8 hours) at 1.0 (0.5) resolution on AMD64x2 with PG Fortran and MPI





MSLP - 24 h forecast

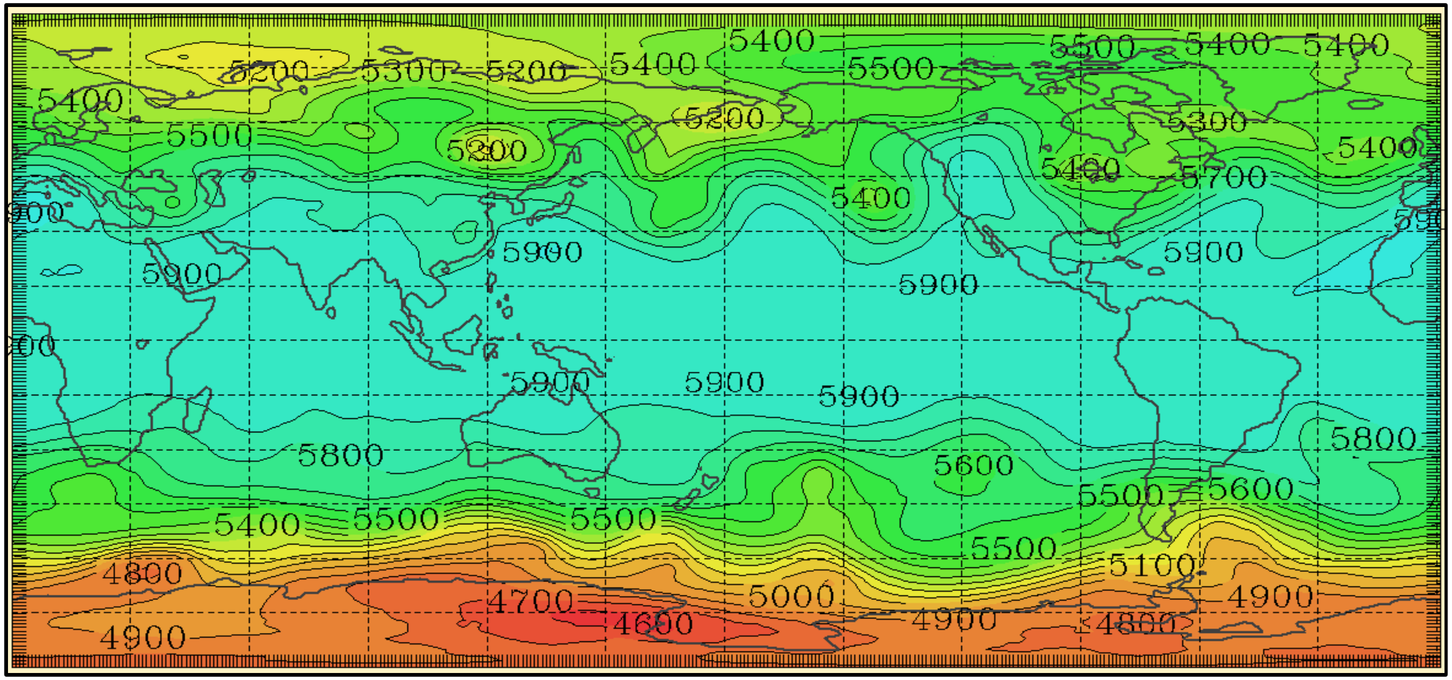
a) GLOBO 1.0 resolution
b) GLOBO 0.5 resolution
c) ECMWF (~ 0.25 resolution)



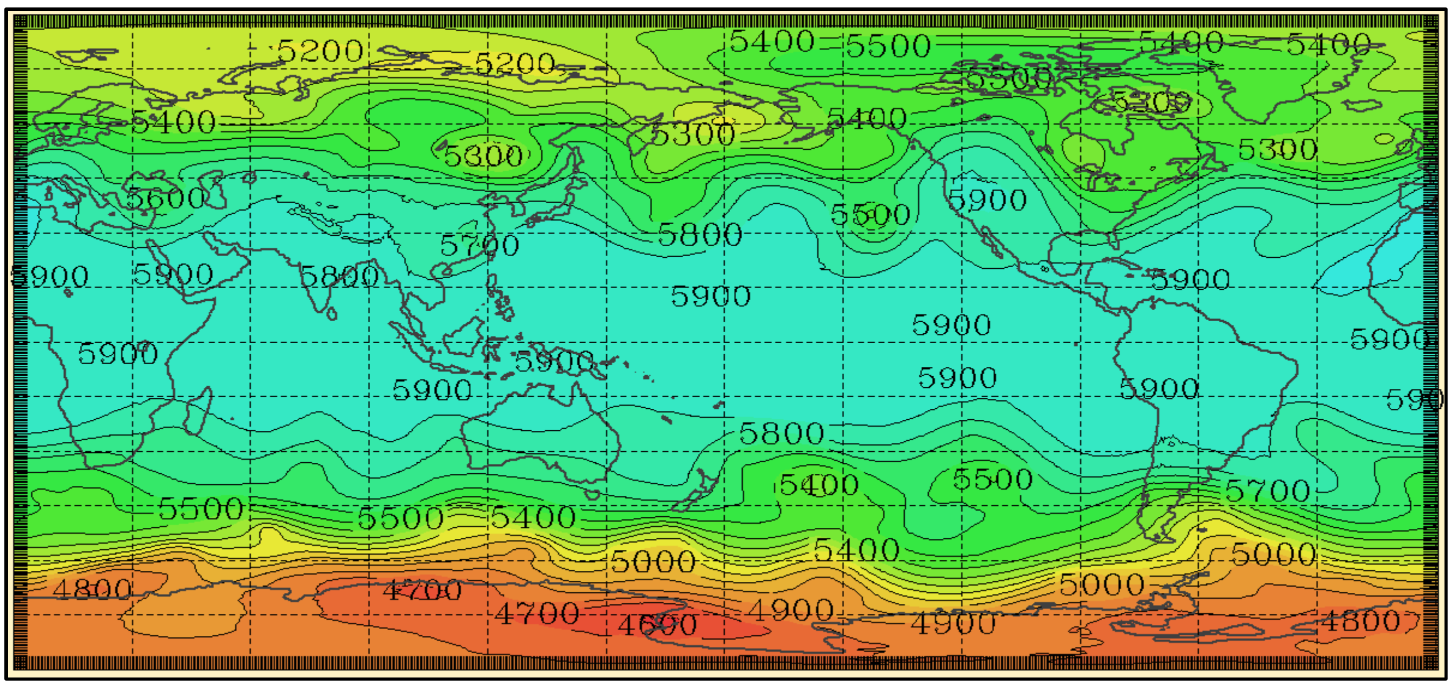
3-days Forecast

GLOBO vs ECMWF
500 hPa geopotential height

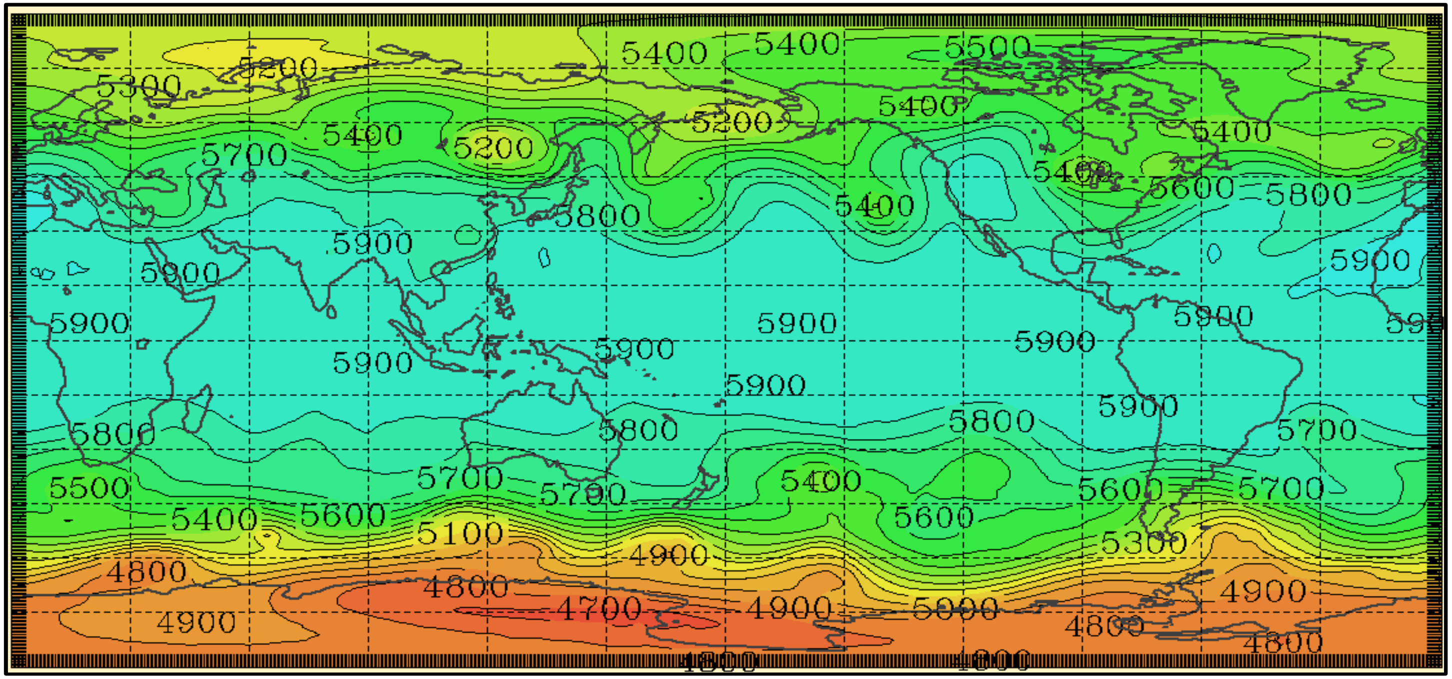
GLOBO 1.0x1.0 res.



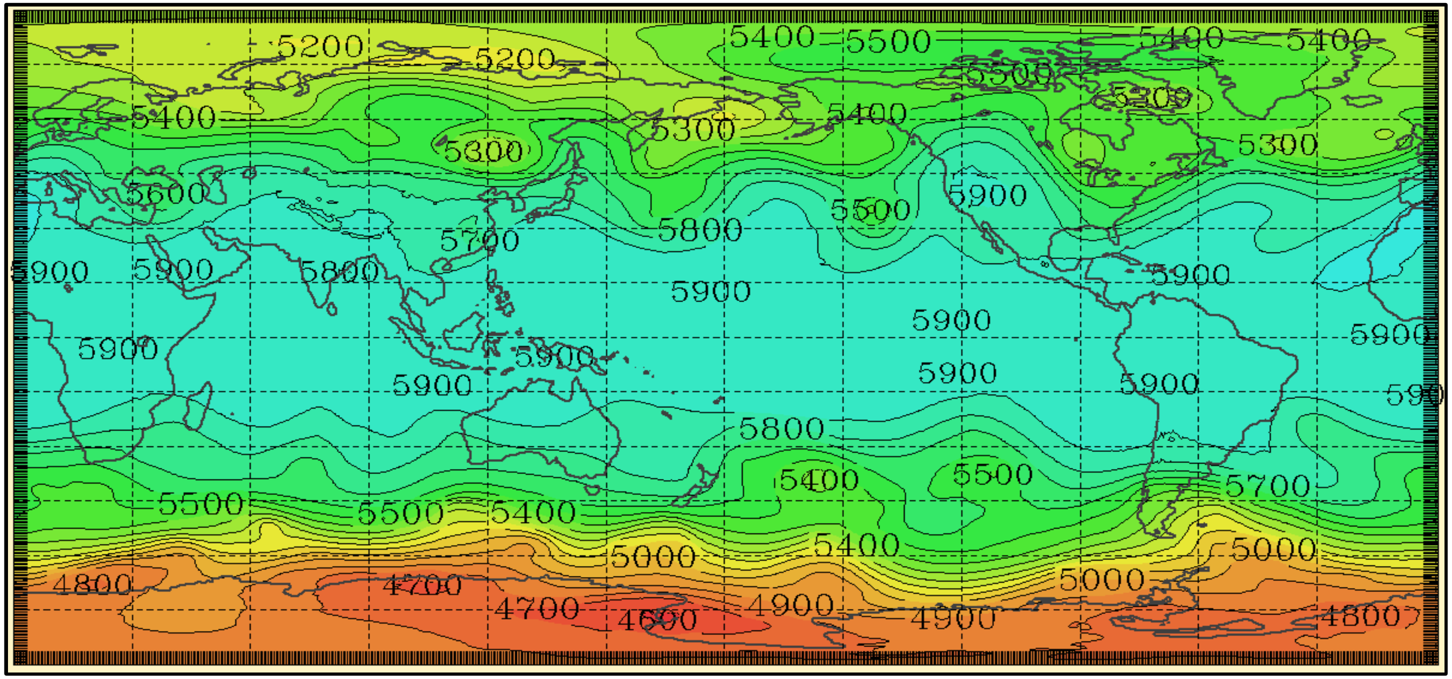
ECMWF



GLOBO 0.5x0.5 res.



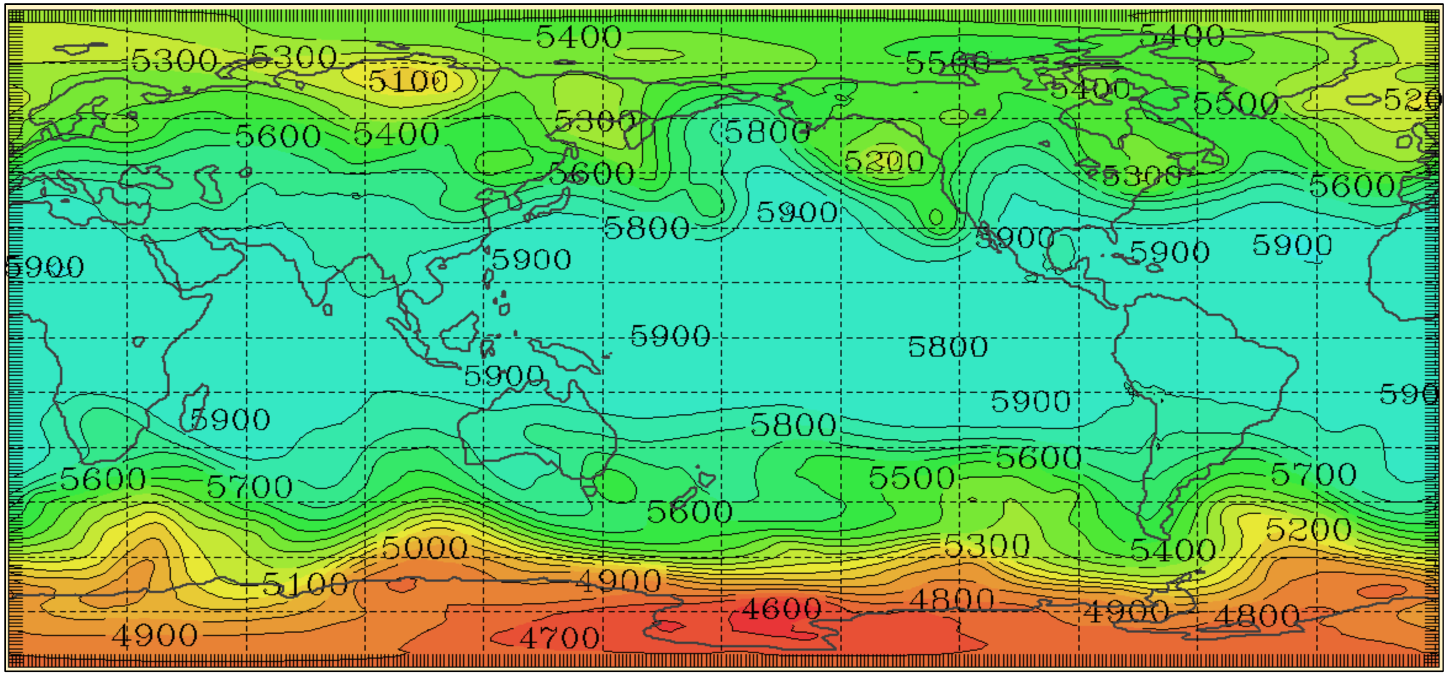
ECMWF



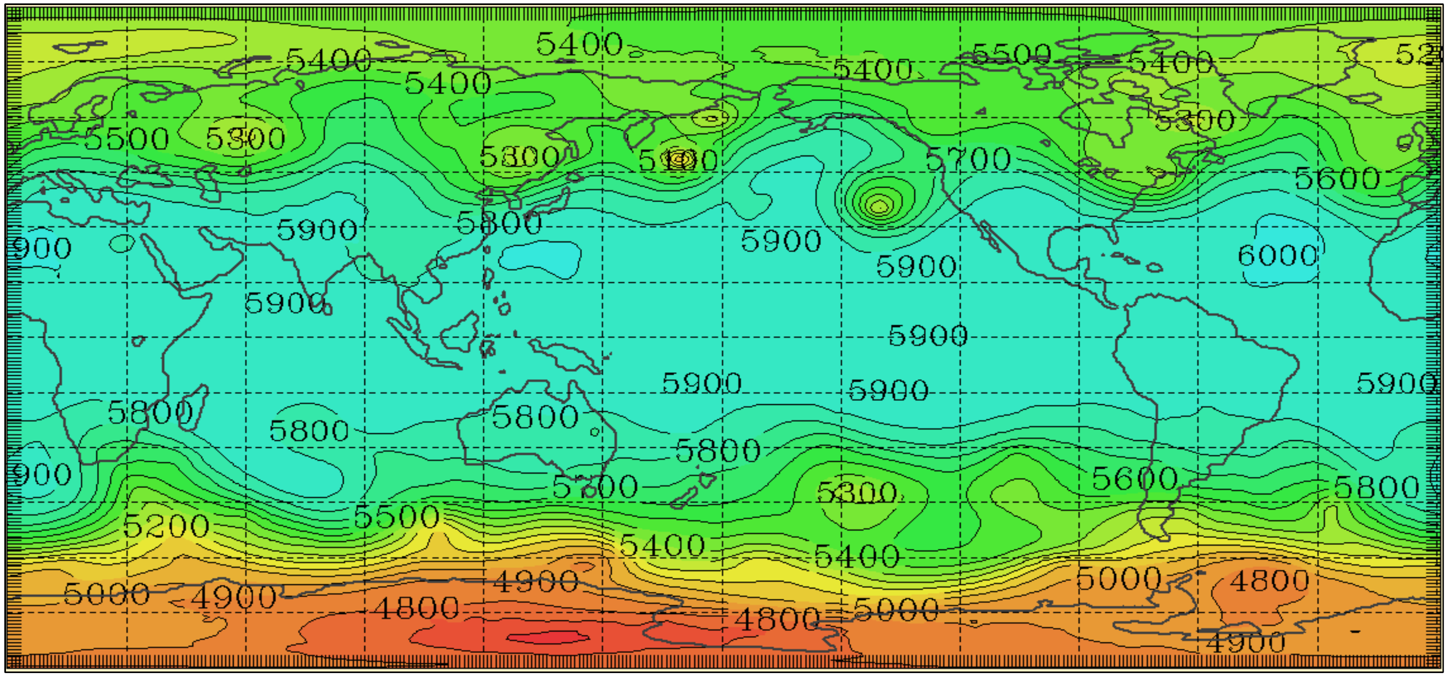
Medium range forecast (7 days)

Comparison of Globo at 1.0 and deg resolution versus the Ecmwf forecast and analysis

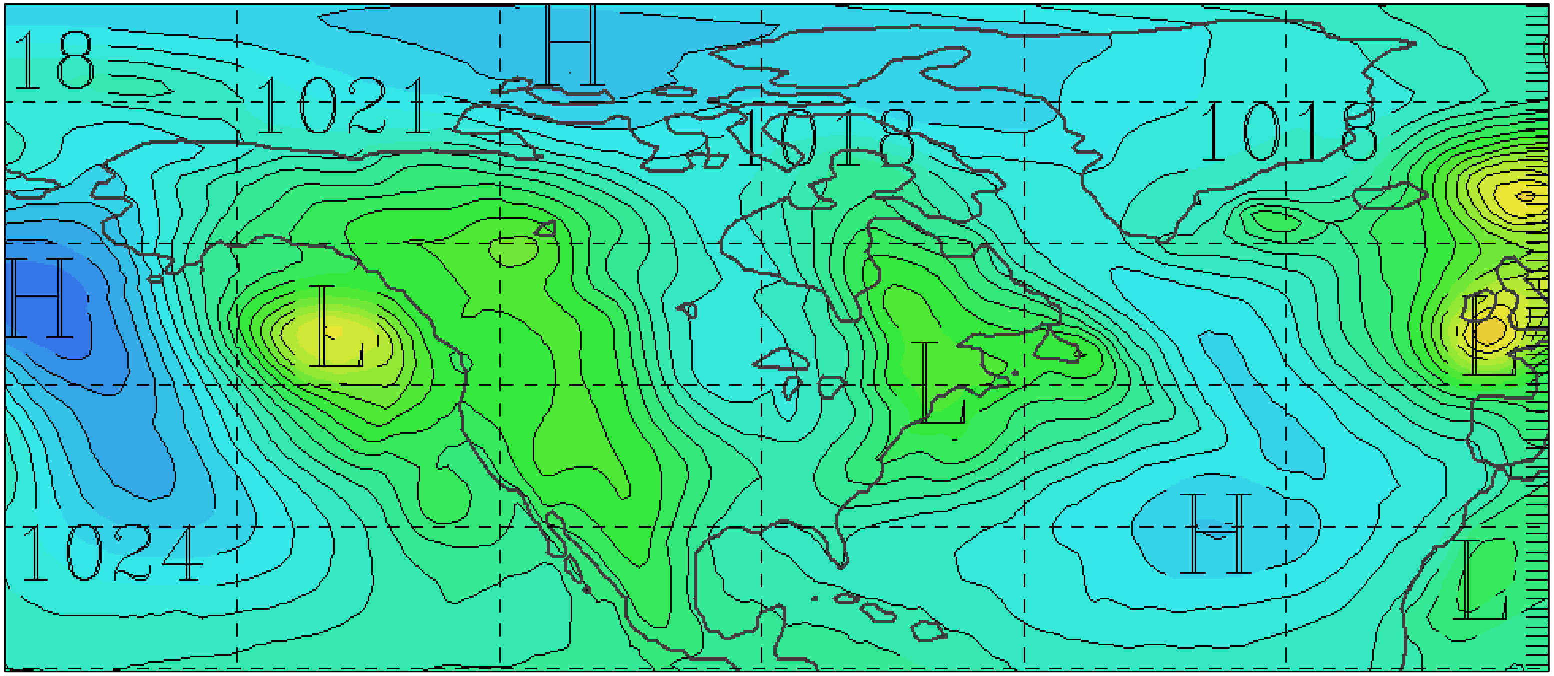
Analysis



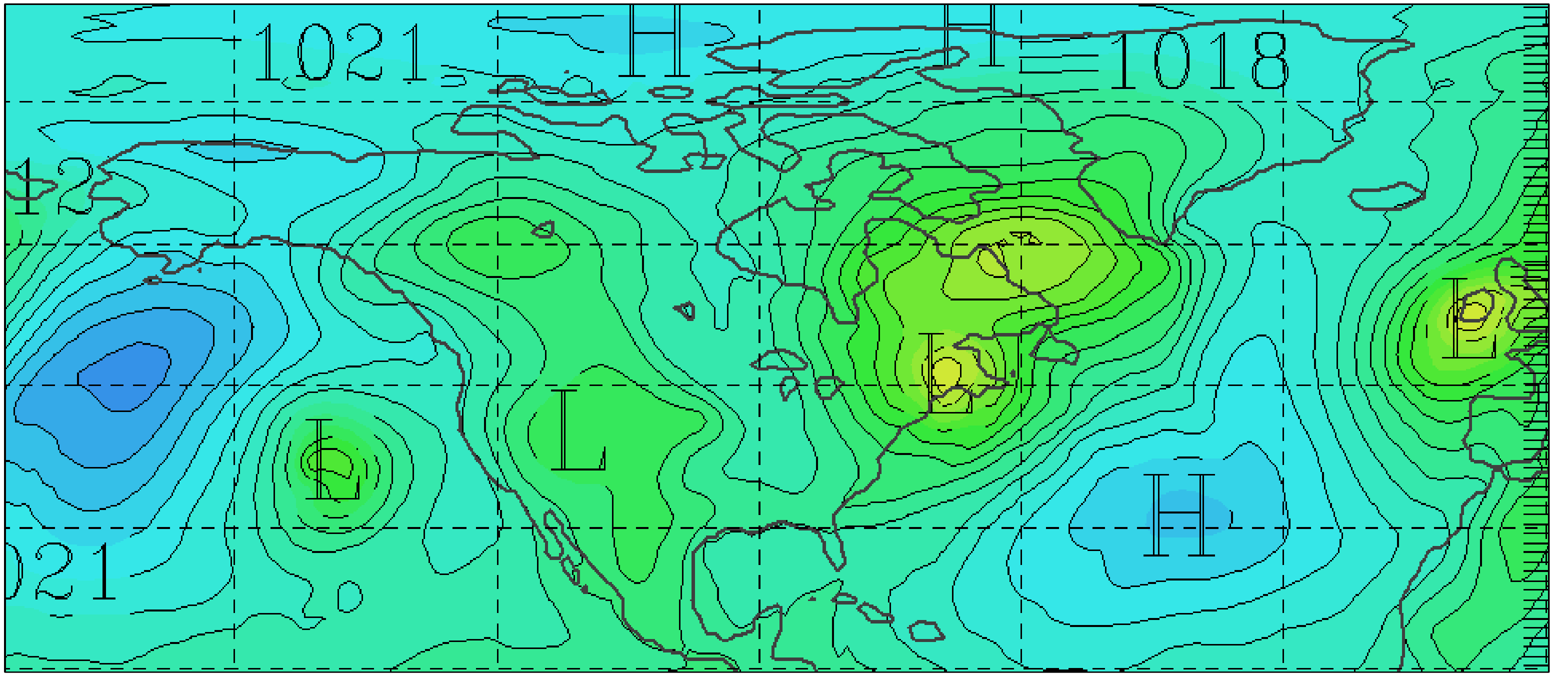
GLOBO 1.0x1.0 res.



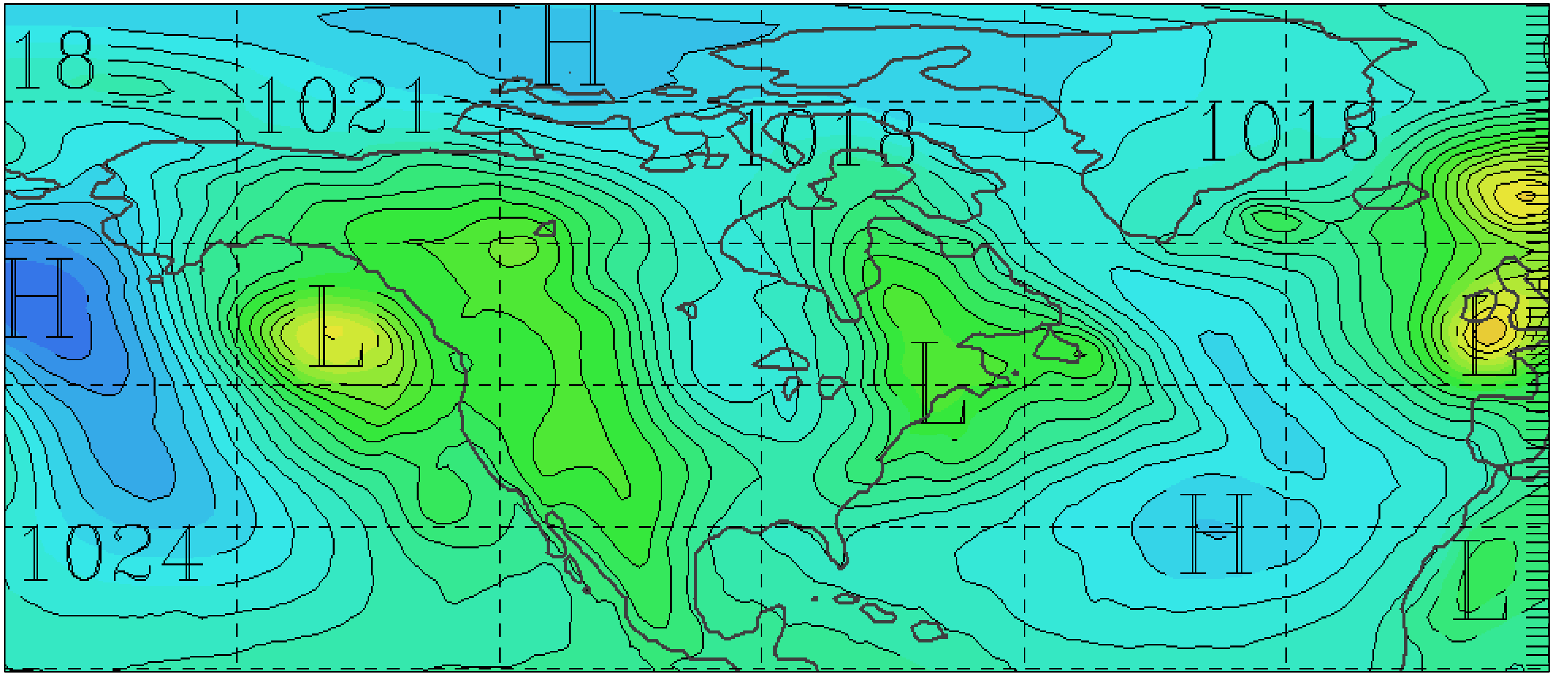
analysis 2006/05/22



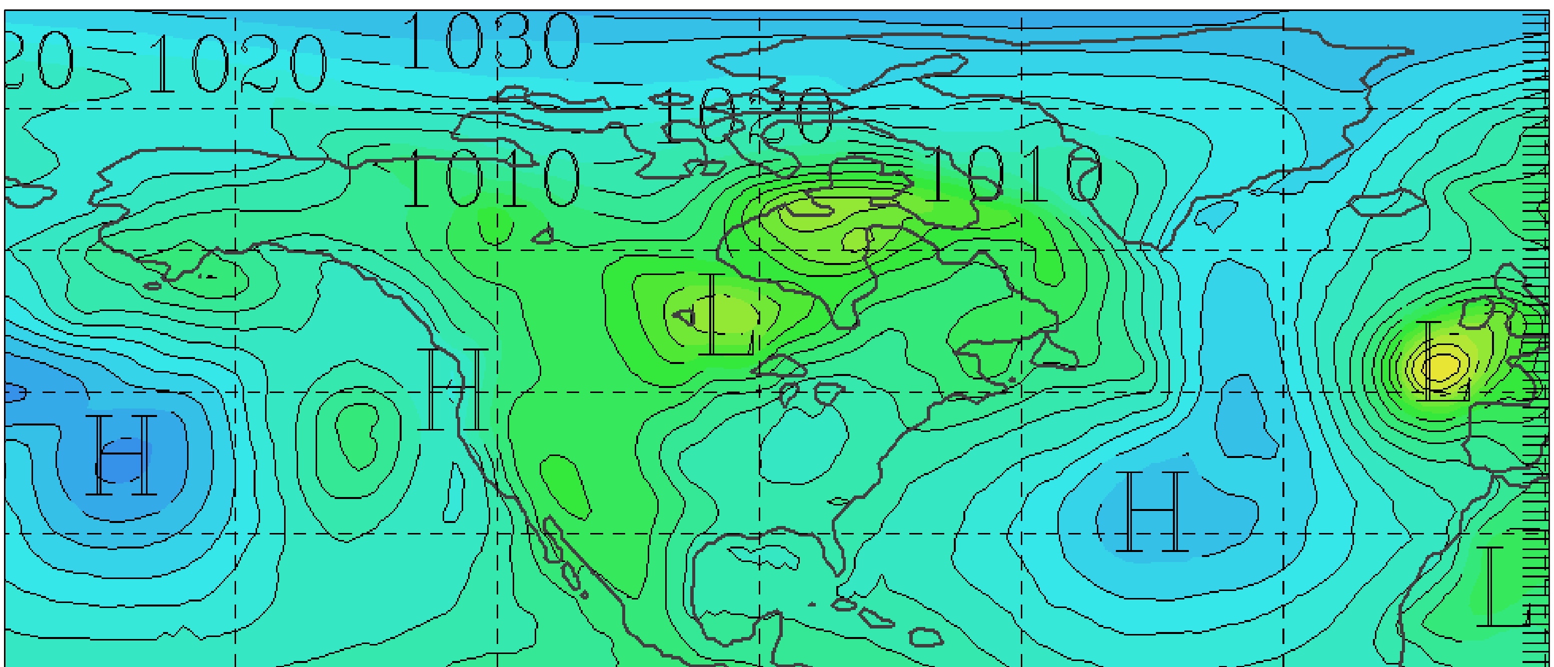
GLOBO 1.0x1.0 res.



analysis 2006/05/22



ECMWF



Objectives

- Develop a tool for medium range weather and ensemble forecast, to be used by weather services;
- AGCM to be used to study the general circulation of the atmosphere (role of water vapour, baroclinic instability, low-frequency variability, planetary waves, ...)
- Tool for seasonal prediction (?)
- Climate model ?