Coupled atmosphere-ocean model for seasonal prediction

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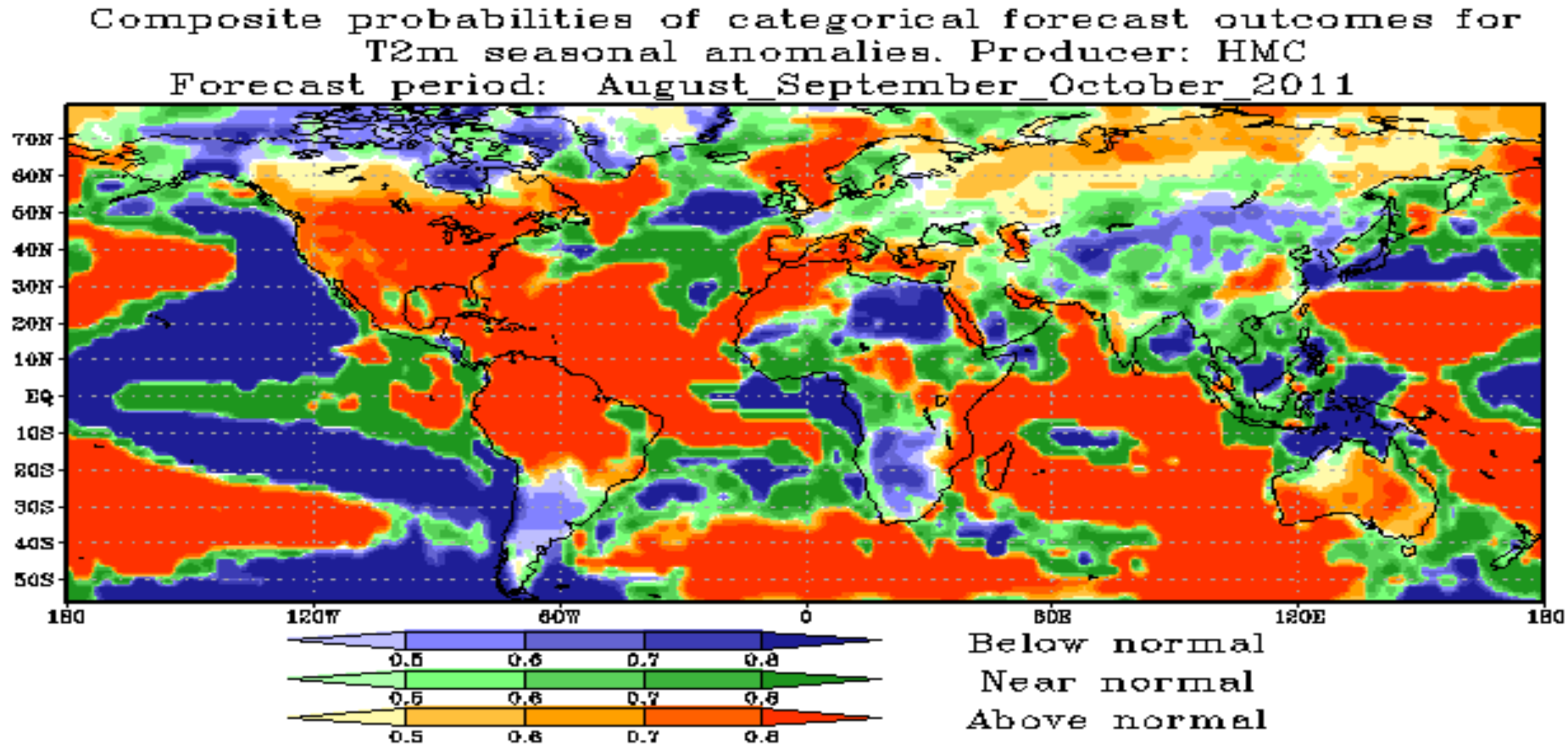
Plan

- Motivation
- Semi-Lagrangian atmospheric model SL-AV
- INM RAS sigma-model for the global ocean.
- Coupling atmosphere and ocean models.
- Numerical experiments and results
- Future work

Seasonal forecast and who needs it

- Forecast of seasonally averaged anomaly with respect to (model) climate.
- Tries to exploit the predictability due to (lower) boundary condition
- Very strong noise, quite low signal. So the use of ensemble technology (perturbed initial data) is required.
- The forecast is often done in categories (‘normal’, ‘below normal’, ‘above normal’).
- Required by agriculture (sum of temperatures), power generation (fuel stock)

Sample forecast (wmc.meteoinfo.ru/season)



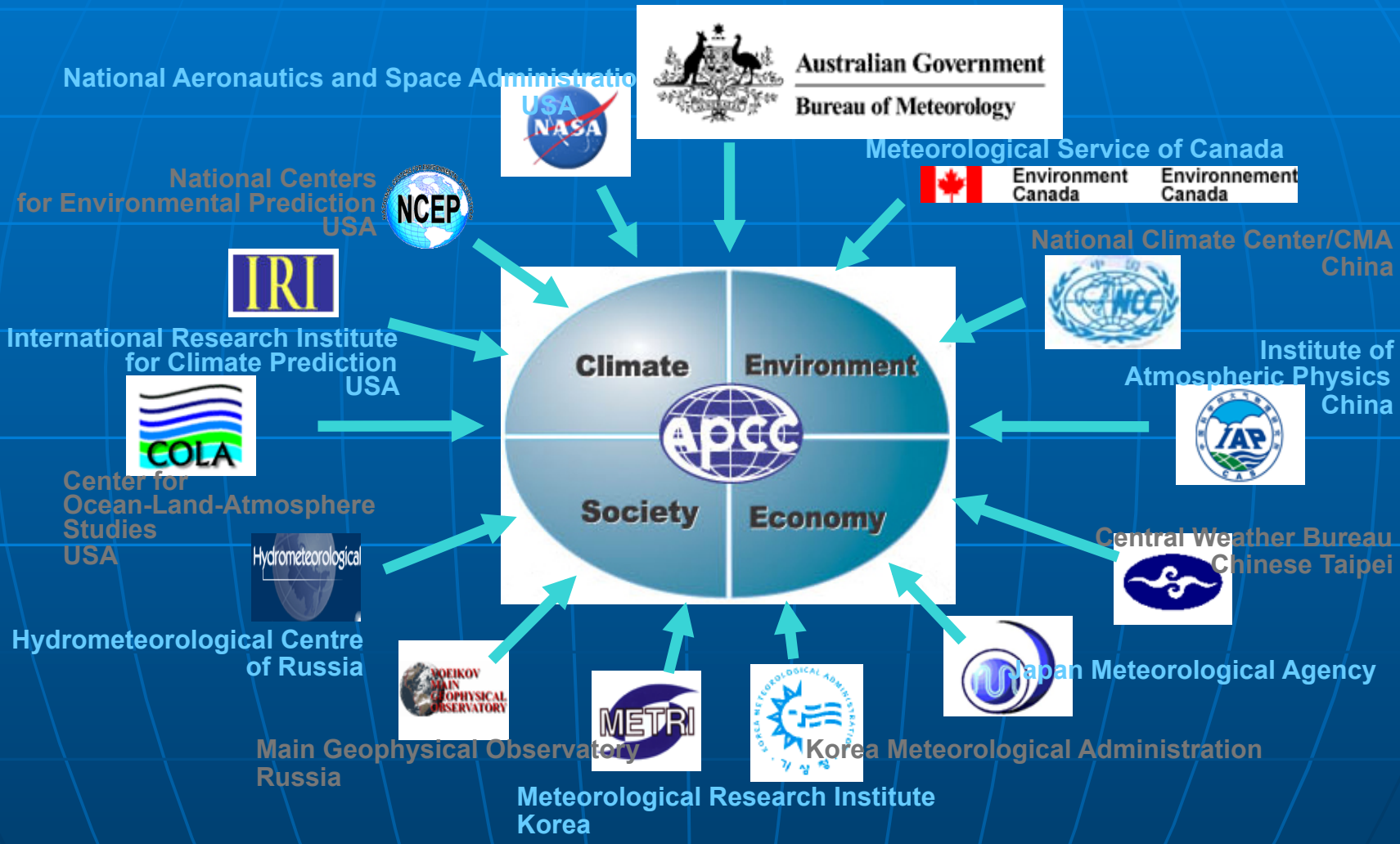
Seasonal forecast

- Is also required by WMO. Hydrometcentre is one of 10 centres in the world providing seasonal forecasts operationally (http://www.wmolc.org/). North-Eurasia Climate Center established in Hydrometcentre supplies CIS countries with seasonal forecasts.
- Usually, atmospheric and soil model, simple extrapolation of SST anomaly.
- Recently, many centres started to develop seasonal forecast systems based on coupled atmosphere-ocean model. Sometimes, full ocean model is used only in tropics, upper mixed layer model is used elsewhere.

Global atmospheric semi-Lagrangian model SL-AV

- Semi-Lagrangian semi-implicit finite-difference vorticity-divergence block for solving dynamics equations of own development
- Parameterizations from ALADIN/LACE model
- Accepted at Hydrometcentre of Russia as the main numerical method for medium-range forecast (0.9x0.72 degrees, 28 levels) and as a component of the probabilistic system for seasonal forecast of climate anomalies (1.4x1.1 degrees, 28 levels)
- Contributes to the South Korean APCC multi-model seasonal ensemble.

Asian-Pacific Climate Centre



Seasonal version of SL-AV atmospheric model

- Resolution 1.4x1.125 degrees lon/lat, 28 levels
- Was presented at CITES 2009
- Description is in (*Tolstykh et al, Izvestia RAN, Ser. PhA&O, 2010)*

Particular features of the seasonal version of SL-AV model

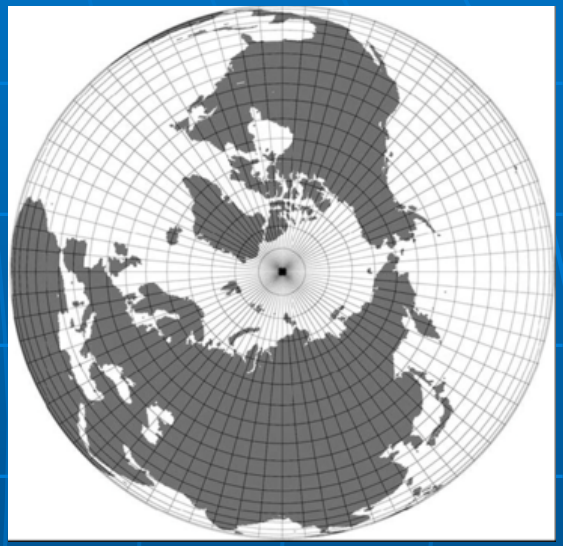
- Stochastic parameterization of large-scale precipitation *(Kostrykin, Ezau, Russian Meteorology and Hydrology, 2001).*
- Hybrid deep convection closure *(Tolstykh, WGNE Res. Act. 2003)*
- Allows to have more realistic precipitation with relatively low resolution.

Ocean model INMOM (Institute of Numerical Mathematics Ocean Model)

Адекватное воспроизведение характеристик Северного Ледовитого океана:

а) использование систем координат с особыми точками за пределами расчетной области

б) воспроизведение характеристик морского льда



Модель океана также может:

(1)воспроизводить гидродинамику океана и характеристики морского льда как при заданном атмосферном воздействии, так и совместно с моделью атмосферы;

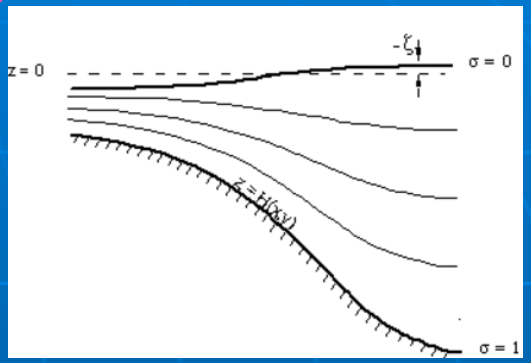
(2)применяться для Мирового океана и его отдельных акваторий с использованием различных криволинейных ортогональных систем координат;

(3)работать на параллельных вычислительных системах.

В качестве вертикальной используется σ-координата:

$$\sigma = \frac{z - \zeta}{H - \zeta}$$

$$Z = \sigma h + \zeta \qquad h = H - \zeta$$



H(x,y) – глубина океана в состоянии покоя
ζ (*x,y,t*)– отклонение уровня океана от невозмущенного состояния

(x, y, z, t) - координаты и время в z-системе

(x_1, y_1, σ, t_1) - координаты и время в σ-системе

Уравнения выводятся с использованием преобразования путем замены частных производных.

$$\frac{\partial}{\partial x} = \frac{\partial}{\partial x_1} - \frac{Z_x}{Z_\sigma}\frac{\partial}{\partial \sigma}, \qquad \frac{\partial}{\partial y} = \frac{\partial}{\partial y_1} - \frac{Z_y}{Z_\sigma}\frac{\partial}{\partial \sigma},$$

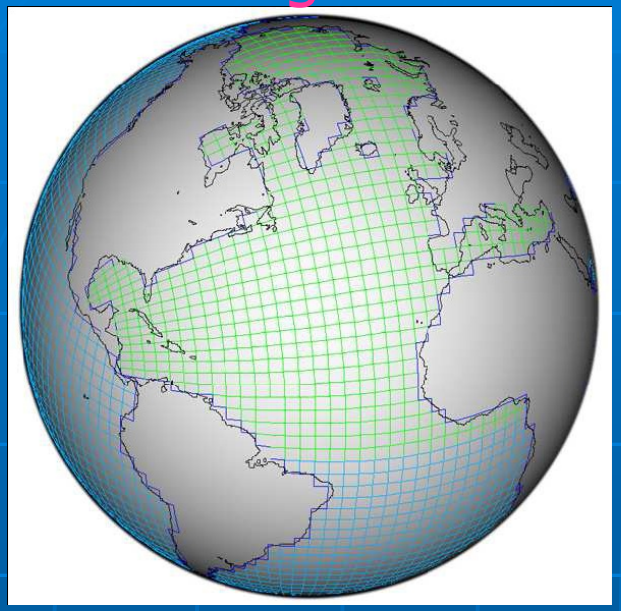
$$\frac{\partial}{\partial z} = \frac{1}{Z_\sigma}\frac{\partial}{\partial \sigma}, \qquad \frac{\partial}{\partial t} = \frac{\partial}{\partial t_1} - \frac{Z_t}{Z_\sigma}\frac{\partial}{\partial \sigma}.$$

$Z = Z(x, y, \sigma, t)$ -геопотенциальная глубина как функция новых (модельных) координат

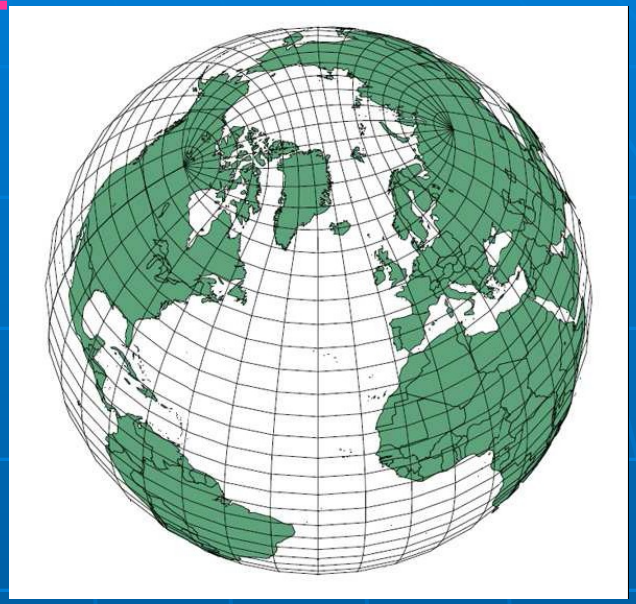
Затем делается приближение $\zeta << H$, и в пространственных производных полагается:

$$Z = \sigma H \qquad h = H$$

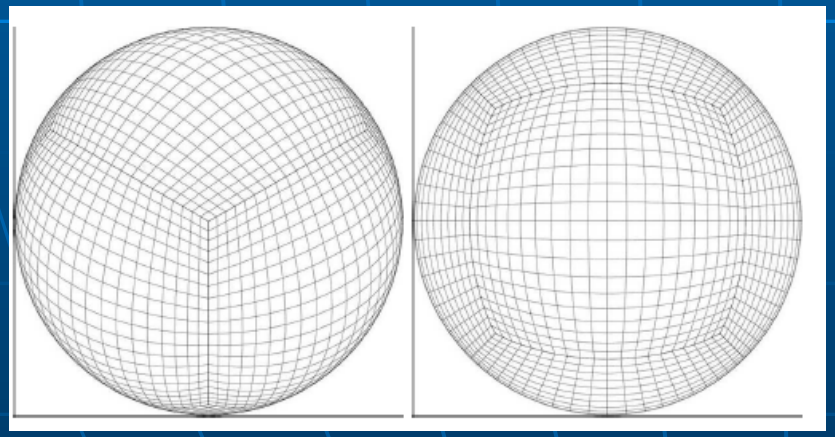
Grids used in global ocean models:



Deleersnijder et al., 1993
Eby and Holloway, 1994



MOM [Griffies et al 2004]

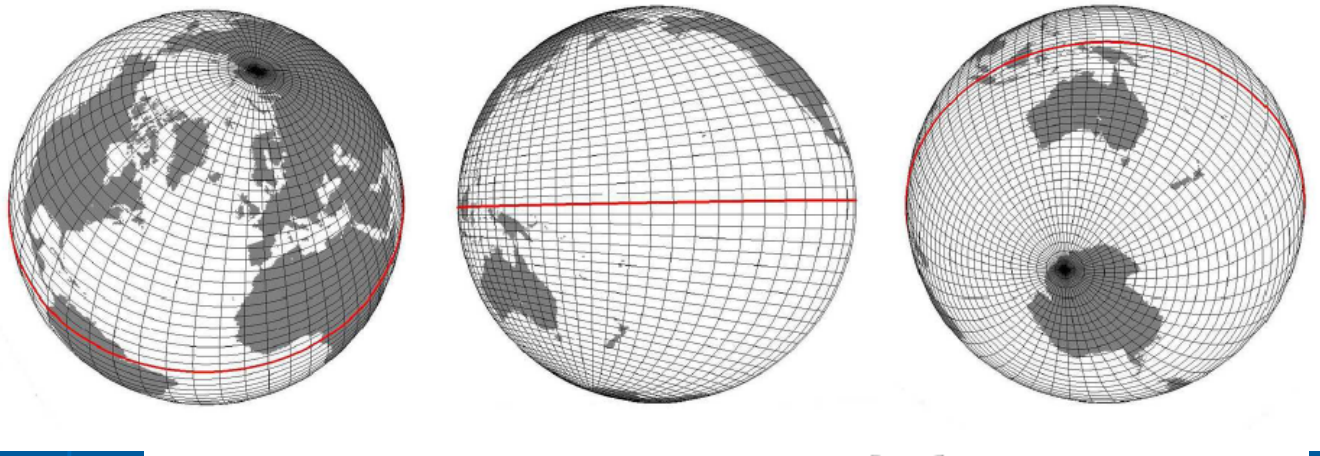


MIT [Adcroft et al 2004]

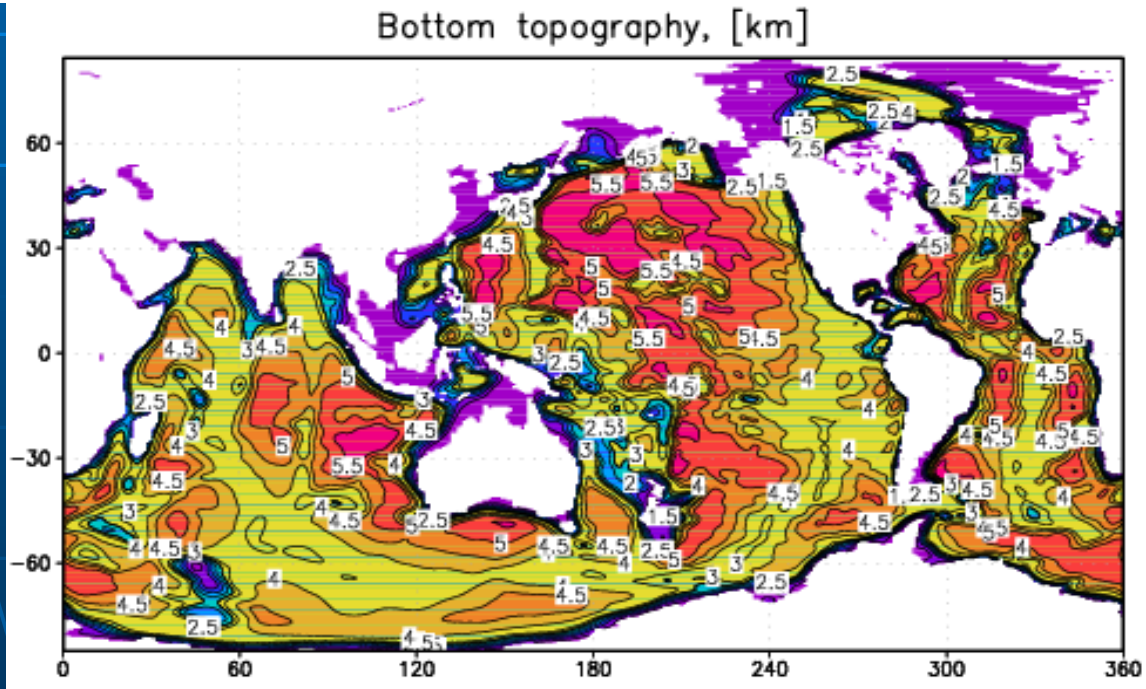
Сухов, 2009
Zalesny and Gusev 2009

Ocean general circulation model, resolution 1°×0.5°×40 in curved coordinate system

Полюса расчетной системы расположены в точках 100°в.д., 70°с.ш. (п-ов Таймыр) и 100°в.д., 70°с.ш.(Антарктида). Экватор совпадает с географическим



1. Ортогональность (по горизонтальным координатам)
2. Аналитичность
3. Расположение особых точек вне расчетной области
4. Сохранение экватора



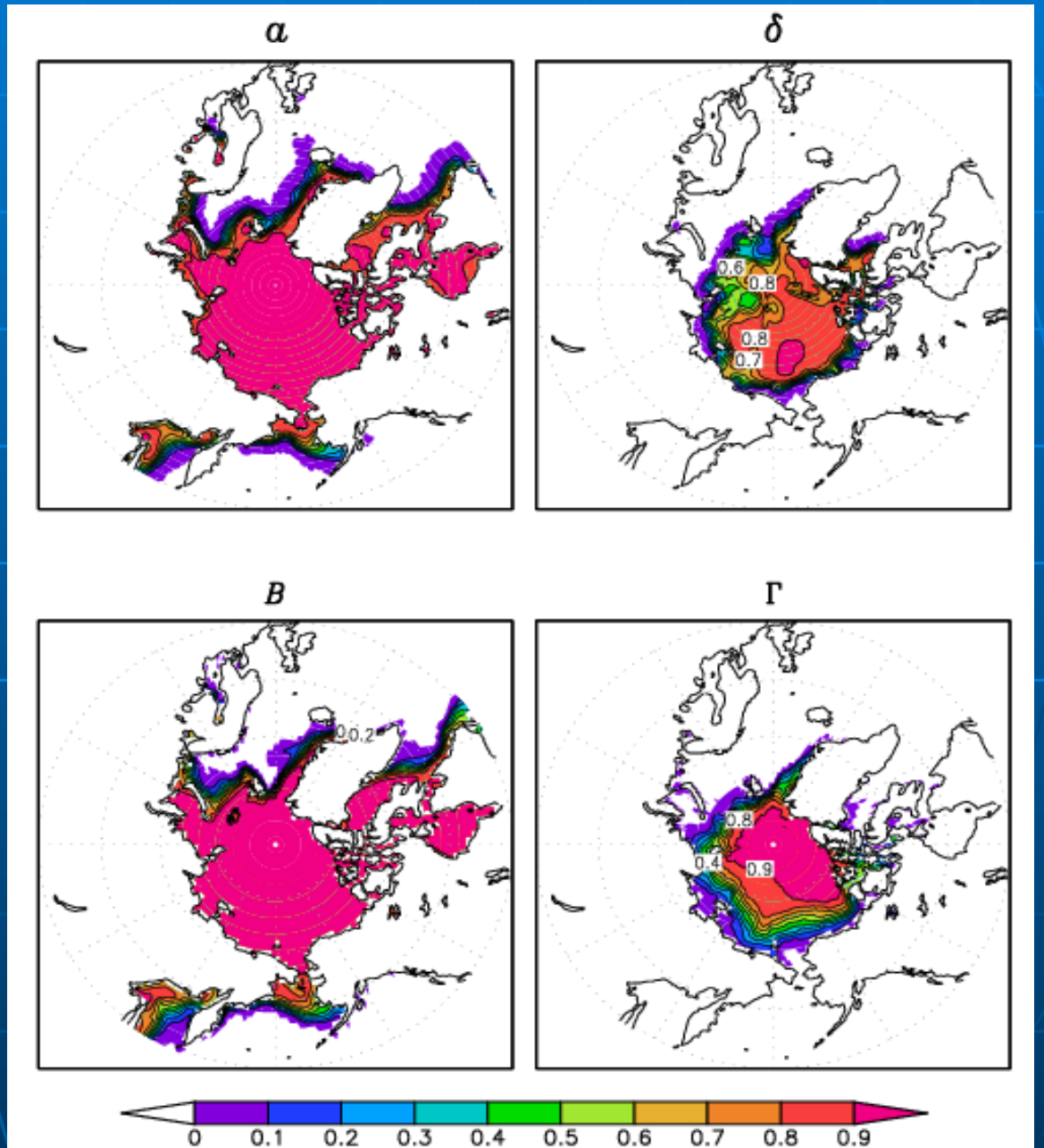
Средняя климатическая сплоченность морского льда в северном полушарии

March

September

Model results

AMIP data [Hurrel et al 2008]



Coupled atmosphere-ocean model for seasonal prediction (1)

- Successive coupling of the models. Simpler technologically. However, limits scalability.
- Parallelized with OpenMP, though the models can use MPI separately.
- Implemented on SGI Altix 4700. Elapsed time to calculate four-month forecast – 4 hours using 8 processors.
- Time step in the ocean model 72 min, in the atmospheric model – 36 min.

Coupled atmosphere-ocean model for seasonal prediction (2)

- Globally averaged over 4 seasons heat flux to the ocean with one-way interaction is 4.5 W/m^2. Model tuning allowed to reduce this value to 2.8 W/m^2.
- Atmosphere and ocean models are coupled without flux correction.
- 10-member ensemble. Only atmospheric initial data is perturbed.
- Seasonally averaged atmospheric circulation of the coupled model for months 2-4 is compared to the results of atmospheric model with simple SST evolution.

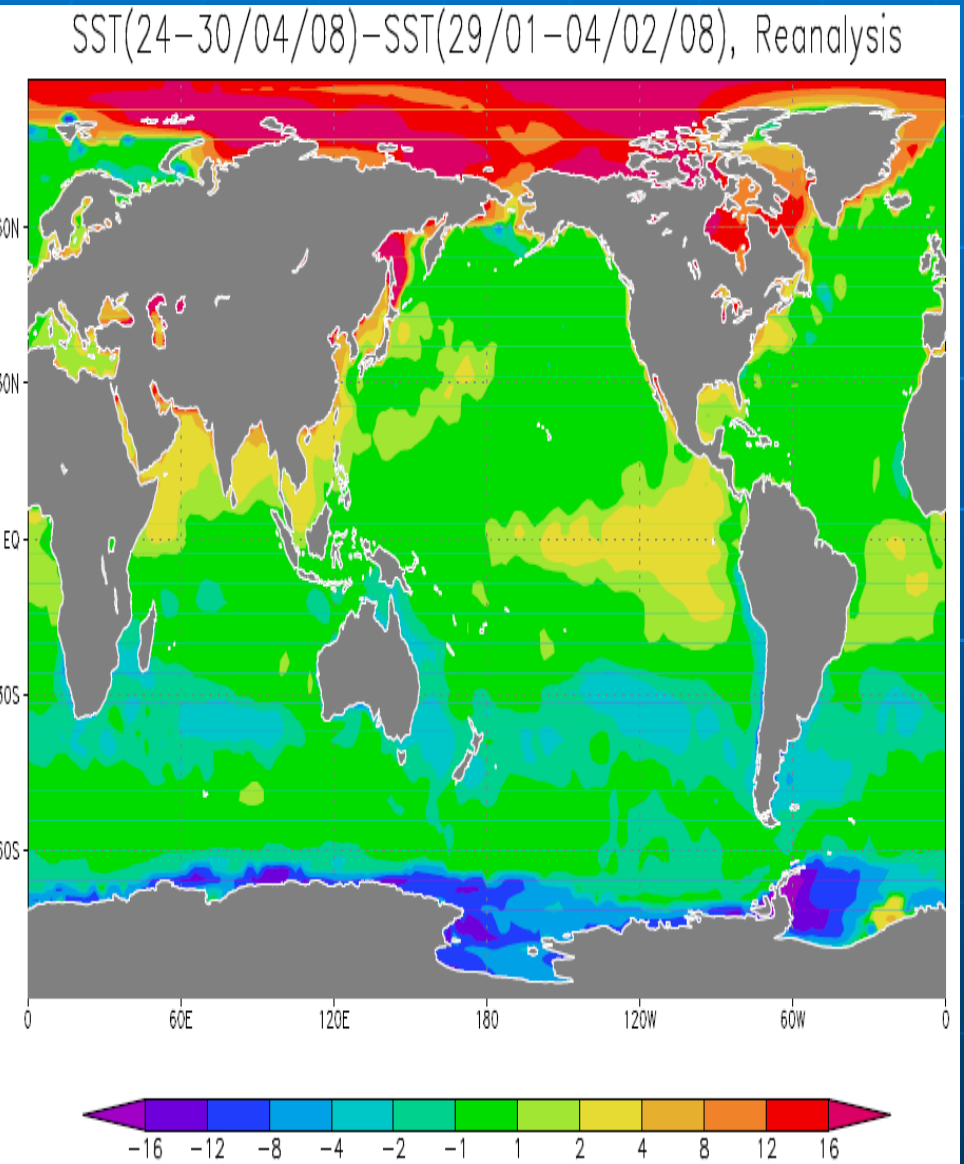
Calculating seasonal hindcasts with the coupled model: Initial data

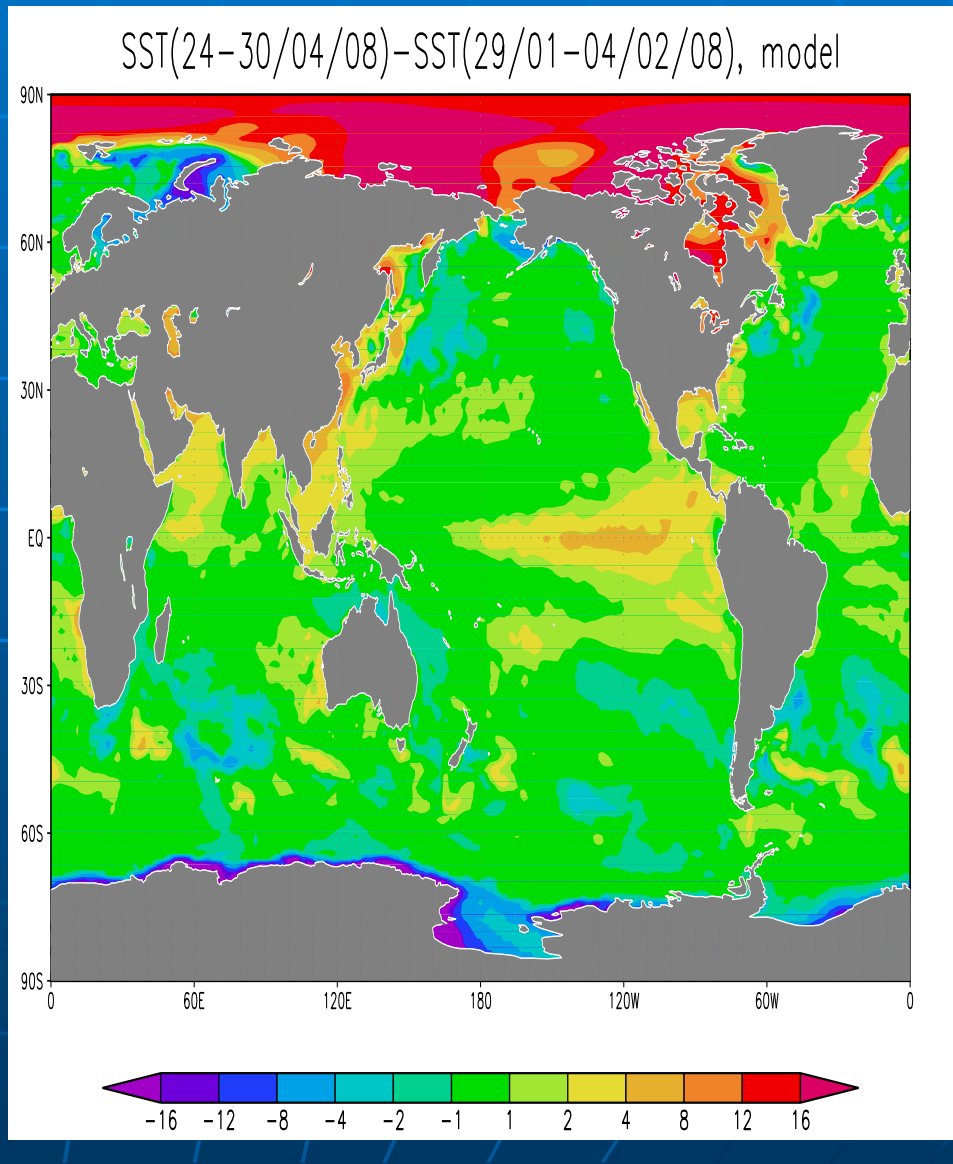
- Running INMOM ocean model for 1989-2010 using ERA-Interim atmospheric forcing. Archiving ocean model state for the moments when historical seasonal forecasts start
- Using NCEP/NCAR reanalysis-2 data in upper atmosphere + SLP as initial data for atmospheric model.
- For soil variables, using own soil assimilation scheme correcting soil variables from T2m and RH2m 6-hour forecast error. T2m and RH2m analyses still come from reanalysis-2.(*Attempts to use soil fields from reanalyses led to bad results, see proceedings!)*

Calculating seasonal hindcasts with the coupled model

- All the seasonal forecasts are with one month lead time, so the coupled model is run for 4 months.
- Running hindcasts for each season of 1989-2008, 10 member ensemble for each hindcast.

SST change in one of the experiments (right), reanalysis (left)

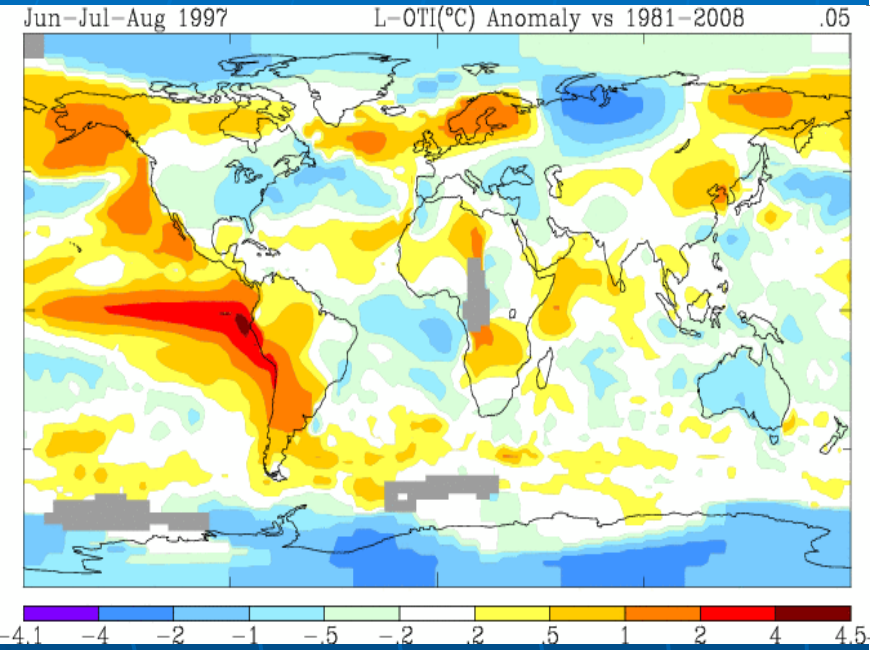


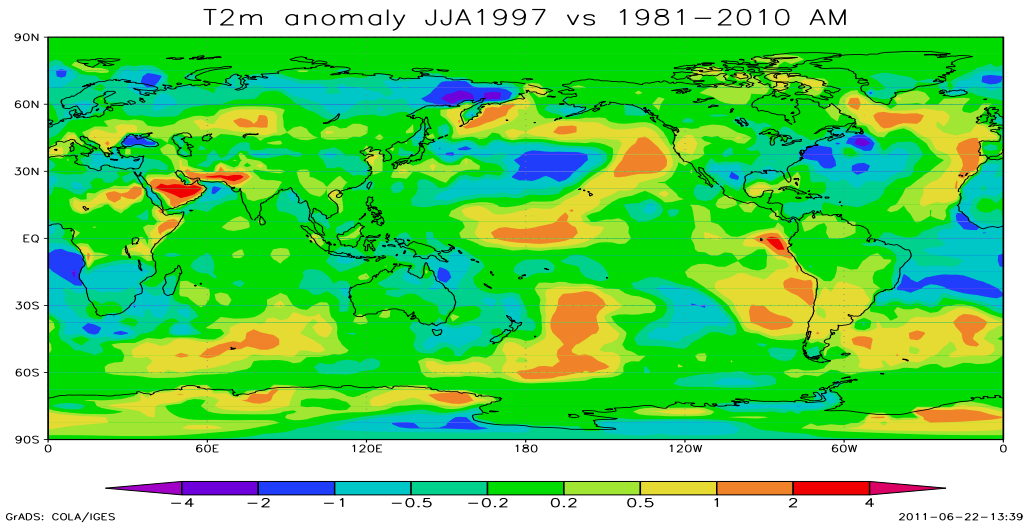


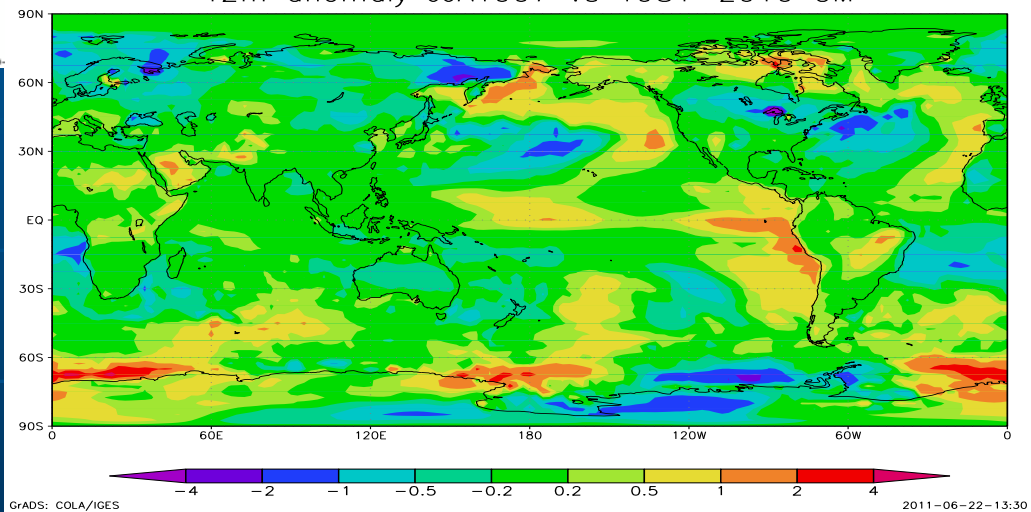
Errors for 500 hPa height (H500) [м], sea-level pressure (MSLP) [mb], temperature at (T2m)[˚C], averaged over 1989-2008 years for all seasons for atmospheric model with SST extrapolation (SLAV) and coupled model (CM). Full fields and model anomaly added to climate (ANOM)

	SLAV RMSE	CM RMSE	ANOM SLAV CORR	ANOM CM CORR	ANOM SLAV RMSE	ANOM CM RMSE
H500						
20-90 N	41.1	40.4	0.992	0.992	27.4	27.0
Tropics	14.2	12.2	0.874	0.892	6.2	6.0
90-20 S	38.9	40.23	0.996	0.996	27.1	27.0
MSLP						
20-90 N	3.23	3.05	0.908	0.917	2.09	1.98
Tropics	1.48	1.49	0.967	0.979	0.68	0.55
90-20 S	5.44	5.48	0.981	0.982	2.59	2.57
T2m						
20-90 N	2.20	2.57	0.996	0.996	1.32	1.34
Tropics	1.25	1.46	0.979	0.985	0.58	0.51
90-20 S	2.37	2.78	0.998	0.998	1.20	1.22

Averaged over summer 1997 observed T2m anomaly, as a deviation from 1989-2003 summers according to NASA (http://data.giss.nasa.gov/gistemp/). The same anomaly with respect to model climate in SL-AV with simple extrapolation of SST anomaly (upper right). The same anomaly in coupled model (lower right).







Conclusions

- Coupled model for seasonal forecasts was developed.
- Historical forecasts for each season of 1989-2008 are calculated using ensemble methodology.
- The results show positive impact of coupled model in Tropics, some positive impact in SLP field in Northern extratropics.

Further work

- Trying to refine initial condition in soil (own assimilation of 2m variables).
- Trying CLIRAD SW radiation parameterization.
- Likely switching to ERA-Interim reanalyses for hindcasts.
- Numerical experiments using ocean data assimilation system developed in Hydrometcentre of Russia.
- Using higher resolution ocean model, more sophisticated ice model.

Thank you for attention!