Long-range forecast of weather anomalies in Northern Eurasia

Долгосрочный прогноз погодных аномалий в Северной Евразии

RSF 21-17-00254

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Sources of predictability at subseasonal scales (Vitart, 2012)

- Sea surface temperature
- Land surface conditions (surface temperature, snow coverage, vegetation characteristics, land use, albedo,
- Madden-Julian oscillation (MJO)
- North Atlantic oscillation – Arctic oscillation (NAO)
- Stratosphere variability (sudden stratosphere warmings, quasi biennial oscillation, …)
- Sea ice, its thickness

El Nino- Southern Oscillation

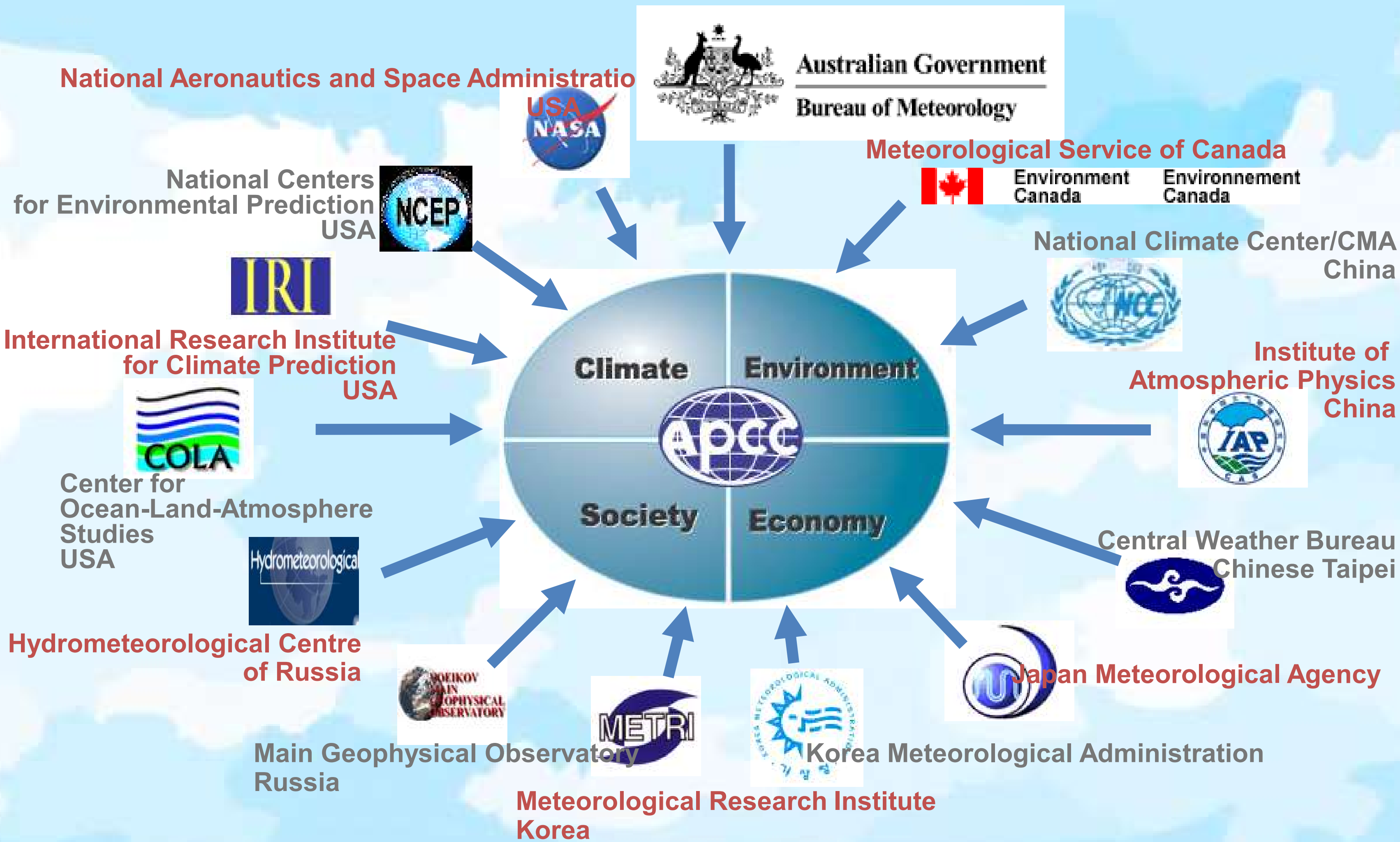
Long-range forecasts

- Lead time greater than 14 days
- Early alert on a probability of some extreme weather event (draught, heat wave,…)
- Customers: power generation, agriculture
- This can be further clarified with a medium-range forecast

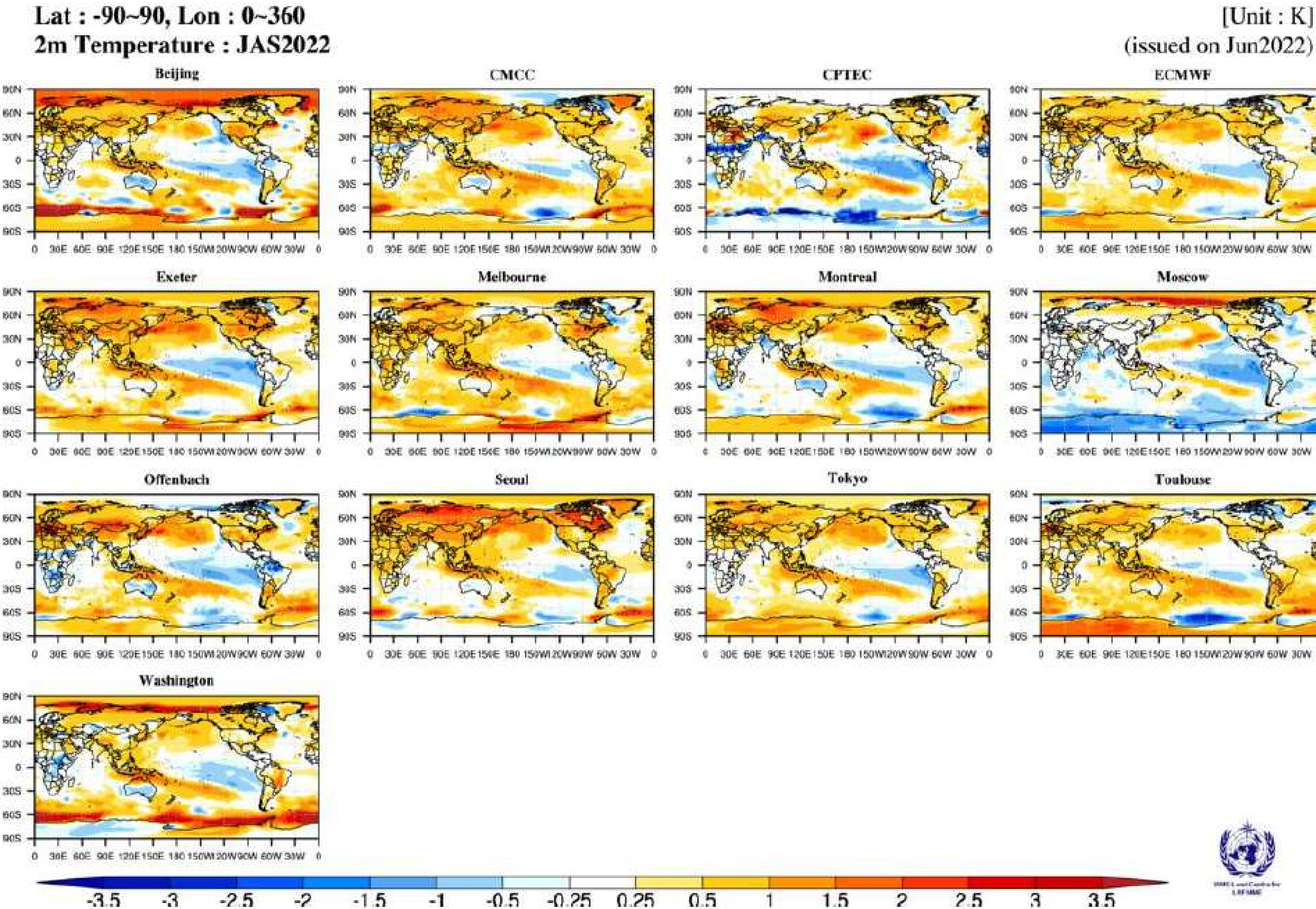
Long-range forecasts (2)

- Only probabilistic and only as an anomaly
- 1. Compute ensemble hindcasts using the same day of 1991-2020 initial data to obtain model 'climate of the day' for all the forecast days
- 2. Compute ensemble forecast with the same model with current initial data.
- 3. Compute the anomaly with respect to model climate.
- 4. Using ensemble, compute probabilities for 'above normal', 'normal', 'below normal' terciles.

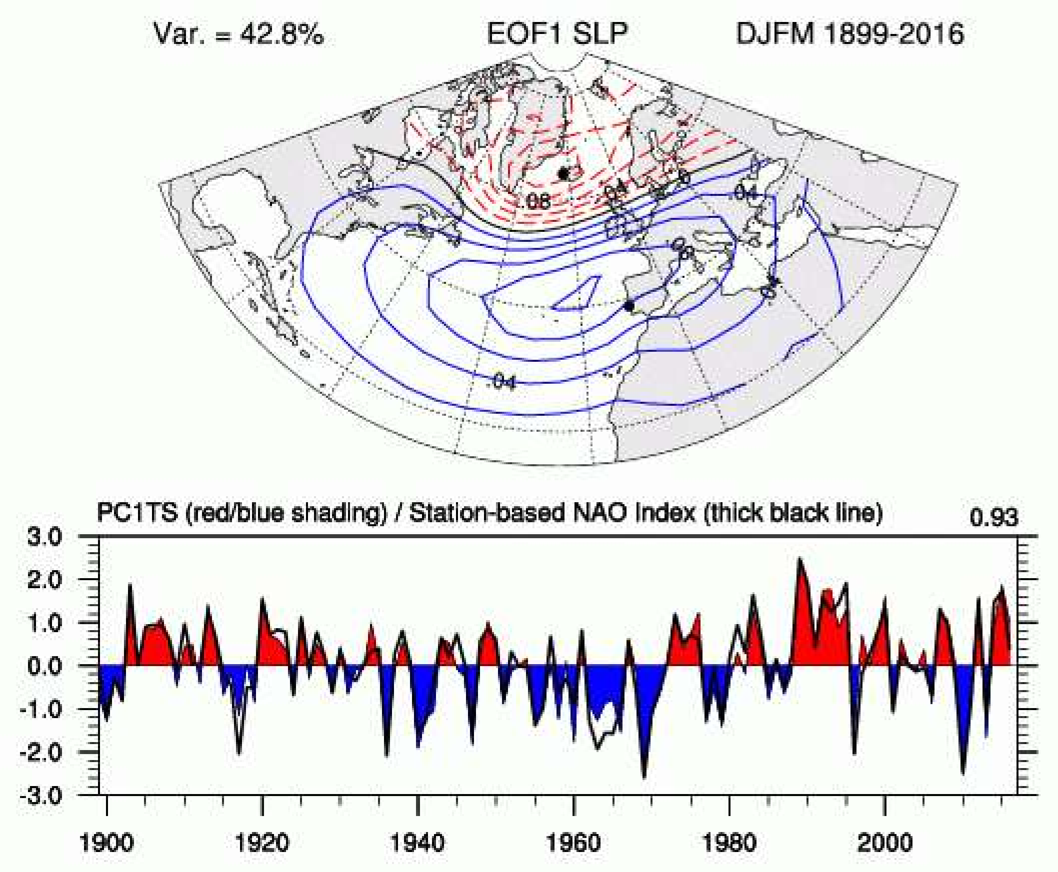
Asian-Pacific Climate Centre



Example of the long range forecast

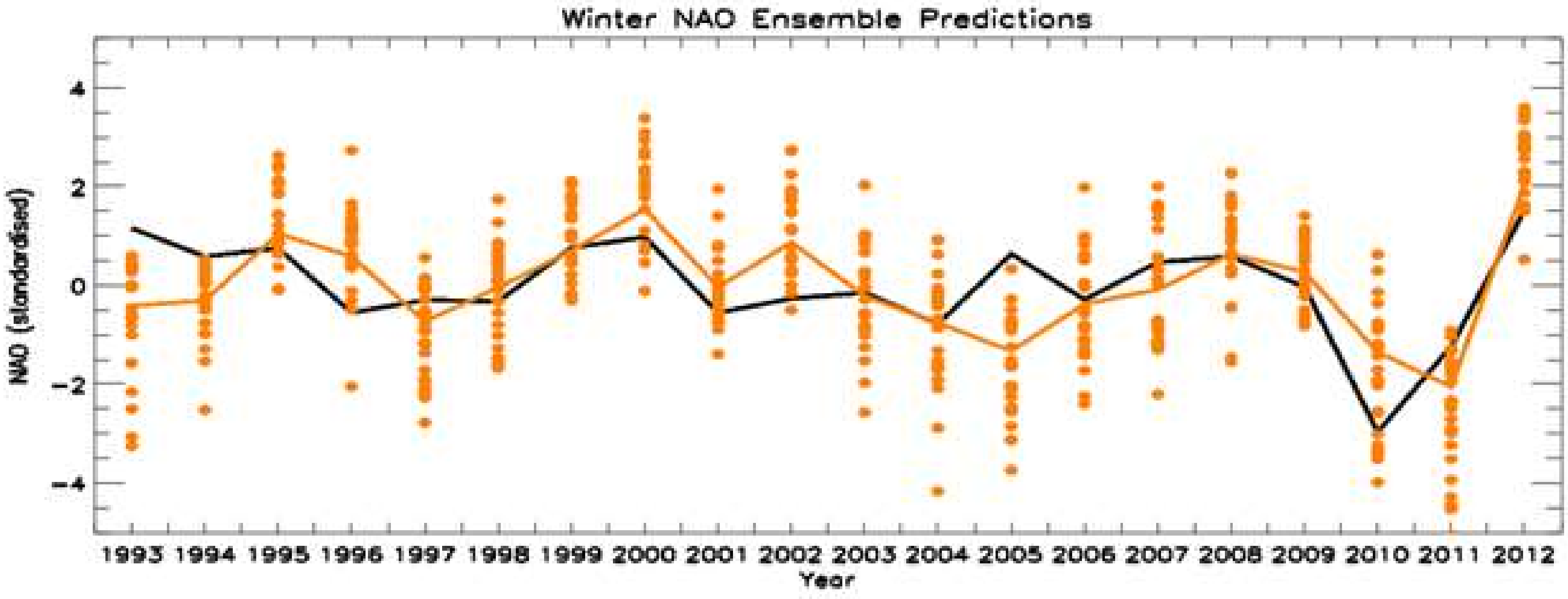


North-Atlantic Oscillation index



Winter index is relatively predictable by the models !

Winter NAO forecasts at theUK MetOffice (A.Scaife)



Correlation score = 0.62

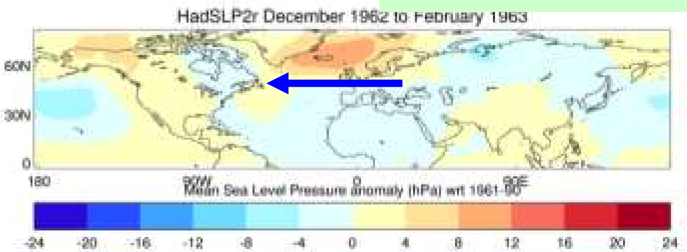
Extended to 20 years and 24 members for DJF

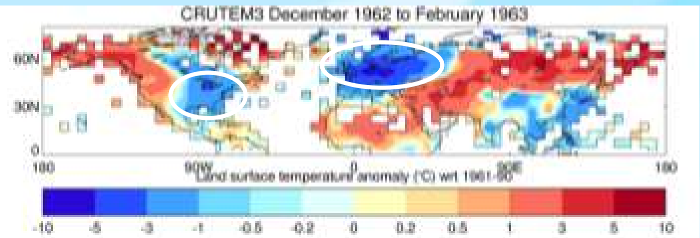
8-10 years ago the correlation at every center did not exceed 0.3 !

Winters depend on which way the wind blows: The North Atlantic Oscillation (A.Scaife)

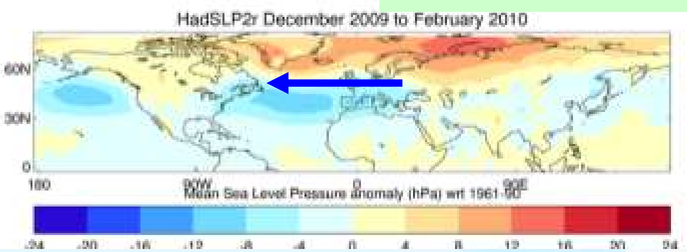
Kryjov (MiG. 2003, 2004)

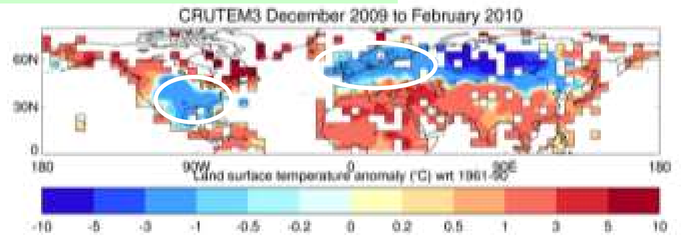
Winter 1962/63





Winter 2009/10



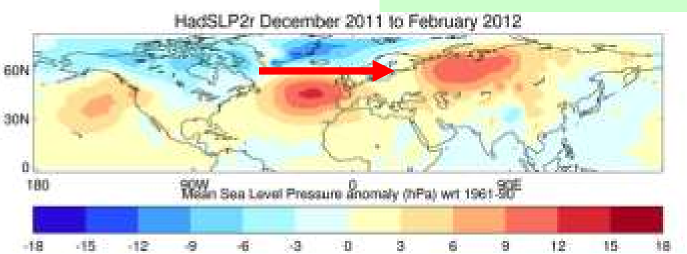


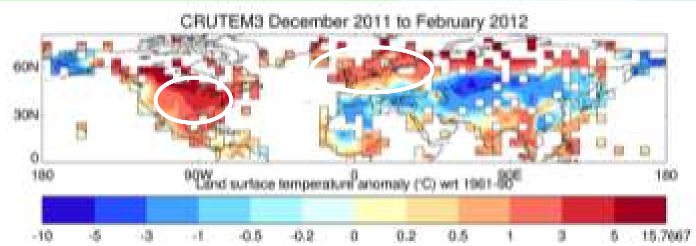
Weak P Gradient

Cold advection into Europe

Cold, calm and dry

Winter 2011/12 c.f. 2013/14!



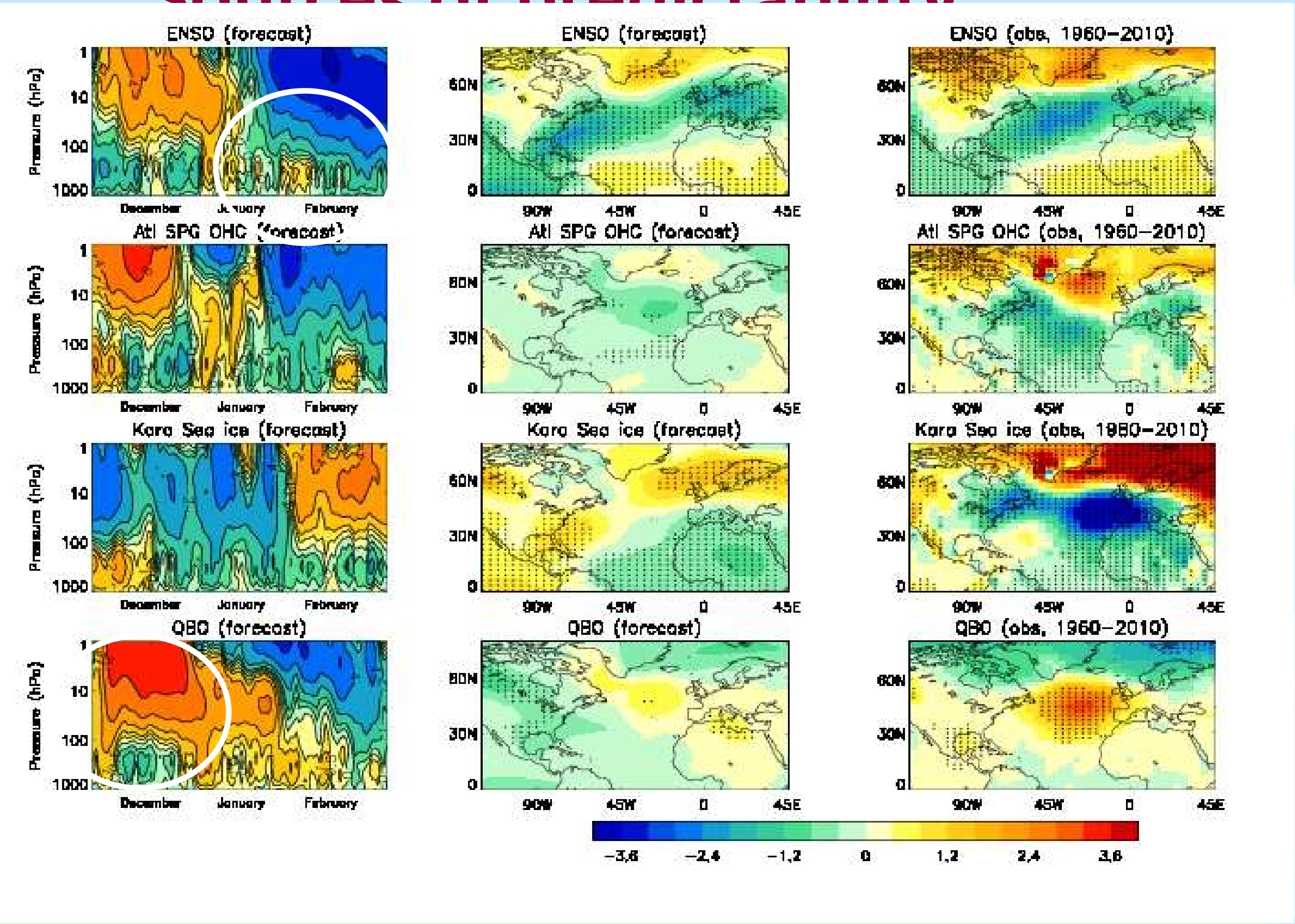


Strong P Gradient

Warm advection into Europe

Mild, stormy and wet

Sources of predictability



Stro

ENSO, Atlantic Ocean, Kara sea-ice and Quasi Biennial Oscillation

Response is weaker in model than obs

Scaife et al 2014

Subseasonal and seasonal forecasts

- 13 WMO Global producing centers
- Russia: Global producing center (HMCR), NEACC (HMCR+MGO). It participates in APCC MME, WMO S2S projects
- Mostly successful in tropics. Mid- and high-latitudes: some spots.
- ‘Smooth’ fields (i.e. MSLP, H500) have higher predictability

Seamless prediction across the scales:

- There are no artificial borders between the scales in the atmosphere (Shukla, 2005; Hoskins, QJ 2013).
- A ‘good’ atmosphere model should reproduce all the time scales correctly inside the same set of parameterizations for subgrid-scale processes.
- «Seamless prediction» models: Germany, UK MetOffice, USA.

- *We extend SL-AV model initially developed for NWP for application on ranges from days to years*

Многомасштабная глобальная модель атмосферы ПЛАВ

Одна из 10 оригинальных глобальных моделей прогноза погоды в мире

Совместная разработка ИВМ им. Г.И.Марчука РАН и Гидрометцентра

Коллектив – 10 человек, соавторы 8 статей в журналах Q1 (2016-2021)

Грант РНФ 21-17-00254; участие 21-71-30023, 14-37-00053, 14-27-00126

Применяется в ГМЦ для оперативного среднесрочного и долгосрочного прогноза

Международное сотрудничество: ECMWF, Meteo-France, Nansen Centre, консорциум ALARO

Климатическая версия развивается в ИВМ РАН

Внутрироссийское сотрудничество: НИВЦ МГУ, ЦАО, ТГУ

Участие в международных проектах ВМО: S2S, YOPPSiteMIP

Russian operational SL-AV model

Federal Service for Hydrometeorology
and Environmental Monitoring
HYDROMETEOROLOGICAL
CENTRE OF RUSSIA

10-days operational medium range forecasts

0.225° in lon, 0.16°-0.24° in lat, 51 levels.
0.1° in lon, 0.08°-0.13° in lat, 104 levels under tuning

LETKF-based ensemble prediction system

0.9° in lon, 0.72° in lat, 96 levels.

Subseasonal and seasonal probabilistic forecast

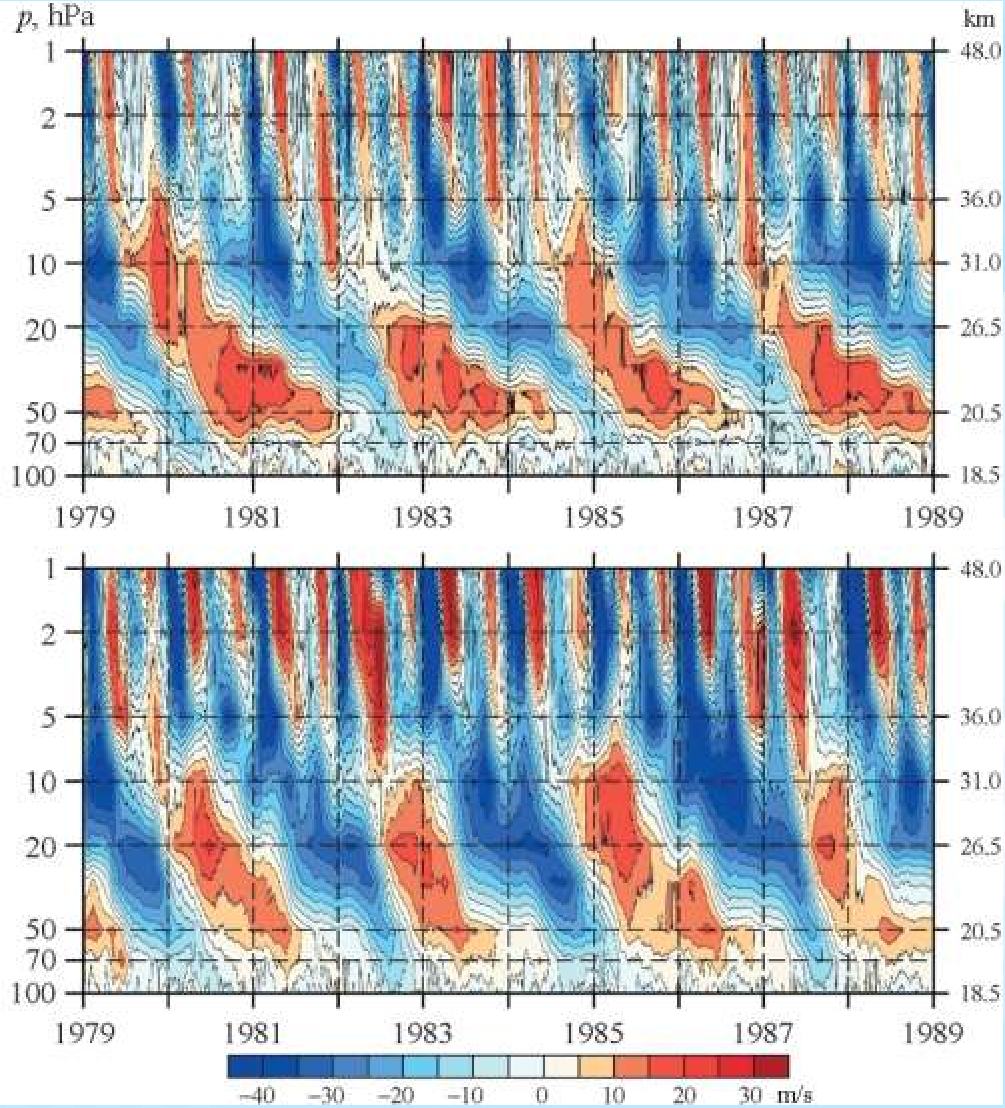
(WMO S2S Prediction project)
1.4°x1.1°L28 currently,
0.9°x0.72°L96, expected next week

SL-AV global atmosphere mod

SL-AV: Semi-Lagrangian, based on Absolute Vorticity equation

- Finite-difference semi-implicit semi-Lagrangian dynamical core (Tolstykh et al, GMD 2017). Vorticity-divergence formulation, unstaggered grid (Z grid), 4th order finite differences. Possibility to use variable resolution in latitude.
- Many parameterizations algorithms for subgrid-scale processes developed by ALADIN/ALARO consortium.
- Parameterizations for shortwave and longwave radiation: CLIRAD SW + RRTMG LW.
- INM RAS- SRCC MSU multilayer soil model (Volodin, Lykossov, Izv. RAN 1998).

Quasi-biennial oscillation in SLAV
(V.Shashkin et al Russ Met. And Hydr. 2019)



SL-AV – top,
ERA I - bottom

Old and new long-range prediction system at Hydrometcentre of Russia

SL-AV 2008

- Resolution 1,4x1,125° lon-lat, 28 levels
- Uppermost level at 5 hPa
- 1.5-3 km resolution in the stratosphere
- SW and LW radiation: Ritter, Geleyn 1992 (1+1 band)
- Boundary layer – improved version of Geleyn 1982
- ISBA surface scheme
- 4 months forecast in 40 min at 8 cores of Cray XC40

SL-AV 2021

- Resolution 0,9x0,72° lon-lat, 96 levels
- Uppermost level at 0,04 hPa
- 500-700 m resolution in the stratosphere
- SW radiation: CLIRAD SW, LW radiation: RRTMG LW (11 + 16 spectral bands)
- Boundary layer: Bastak-Duran et al JAS 2014
- Marine stratoculumus, sea-ice T
- INM RAS multilayer soil scheme
- 4 months forecast in 88 min at 128 cores of Cray XC40 (1 member)

RSF 21-17-00254 grant goal

- Improved forecast of extreme winter colds and summer heat waves over Northern Eurasia

To do this:

- Improve stratospheric circulation in the SL-AV model
- Improve simulation of Madden-Julian oscillation
- Improve teleconnection reproduction
- Improve soil memory mechanism in the model

Key processes to be addressed

- Large-scale wave processes;
- Deep convection parameterizations;
- Stratosphere dynamics and ozone cycle ;
- Surface and soil processes.

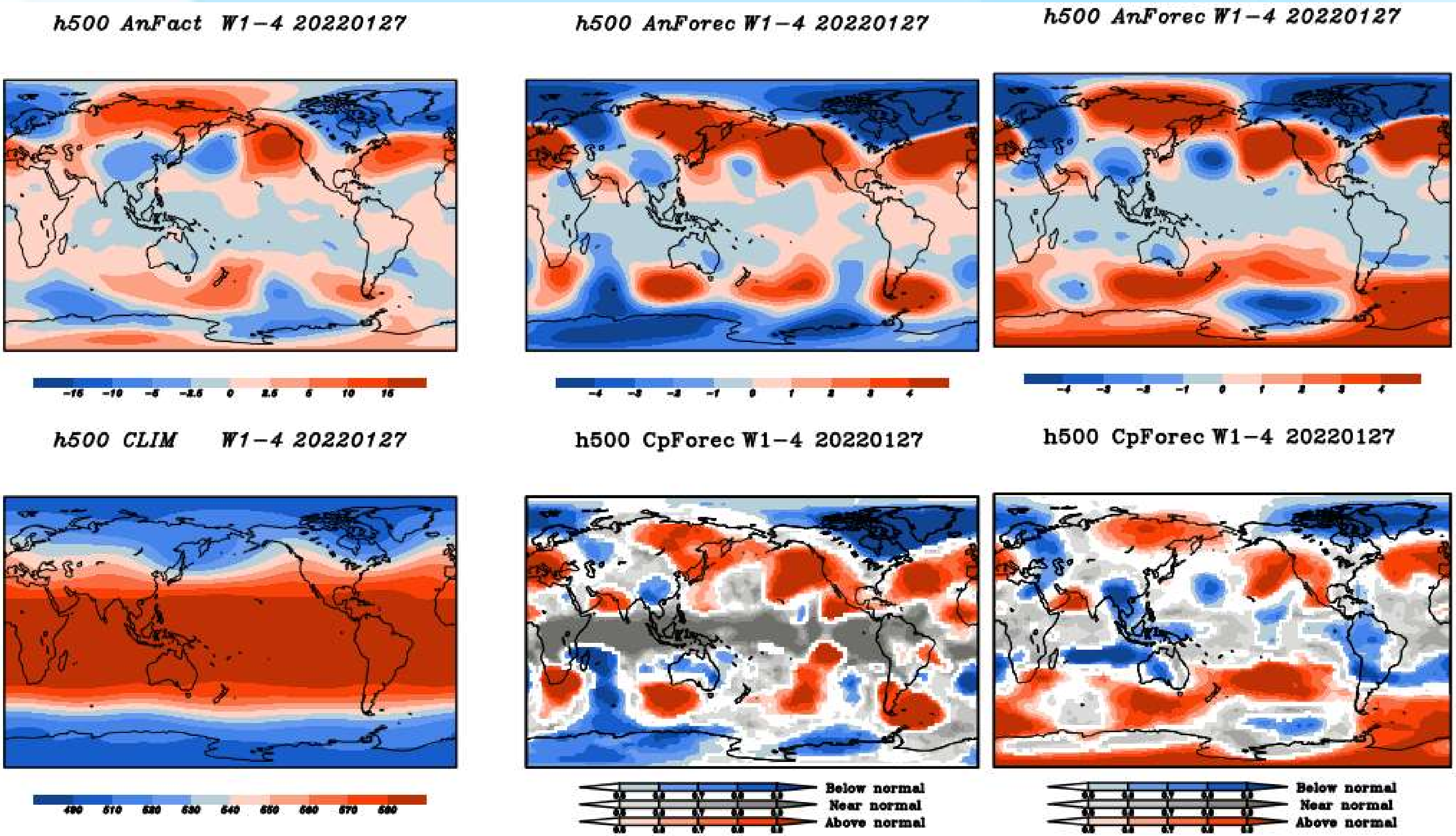
RSF grant 21-17-00254 tasks

- Implementation of CHARM model for photo-chemical reactions (ozone cycle)
- Improvements in INM RAS-MSU soil model
- Implement MSU lake model
- New deep convection parameterization
- Tiling in the model
- New statistical postprocessing scheme

- Not included in the grant but necessary: complex model tuning

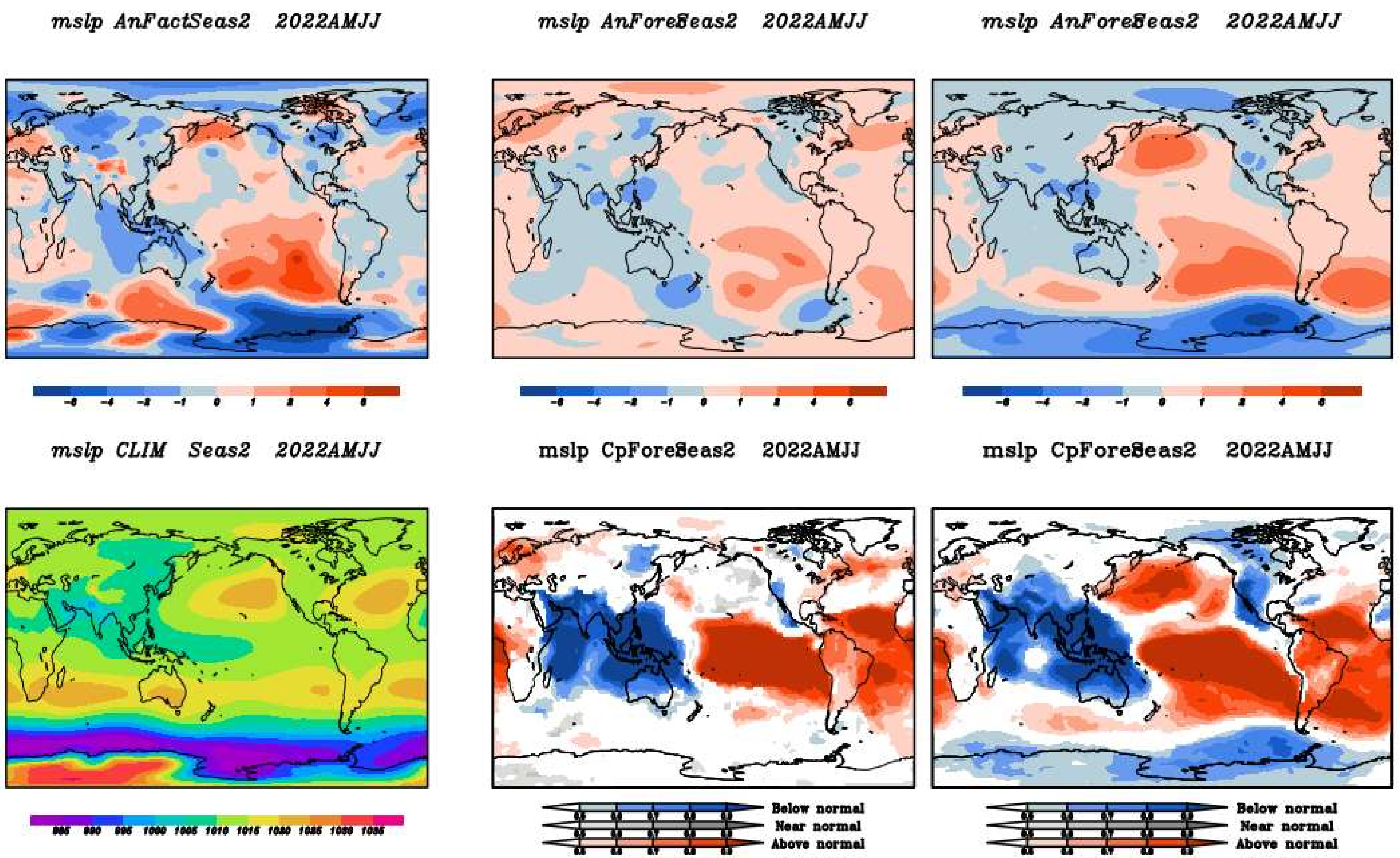
Monthly forecast by old and new versions (4day lead time, Feb2022)

Real anomaly OLD NEW



Seasonal forecast by old and new versions (1month lead time, MJJ)

Real anomaly OLD NEW



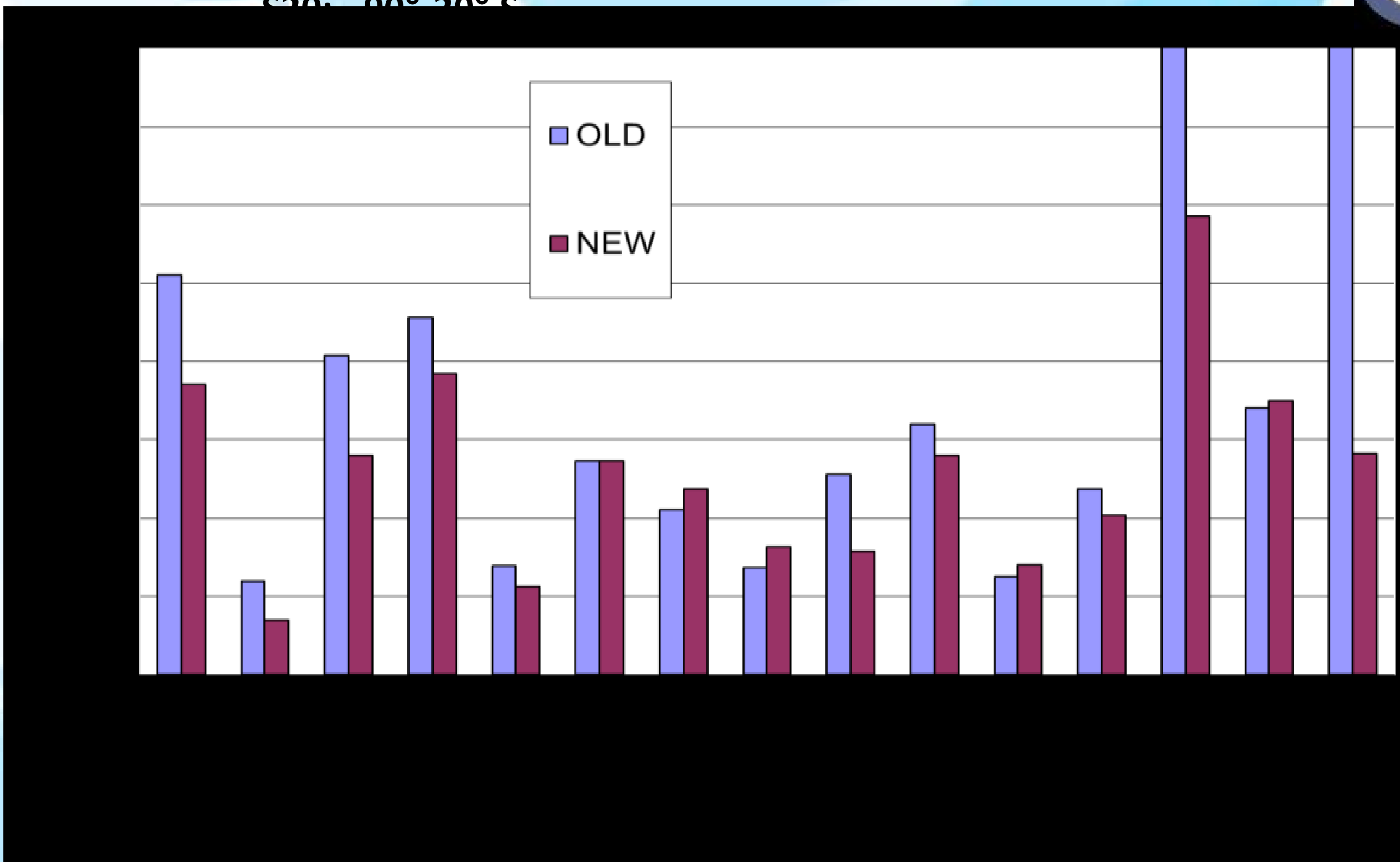
Comparison of RMS errors for winter hindcasts: SL-AV 2015 and 2021 versions

1991-2010 ensemble forecasts, 10 members

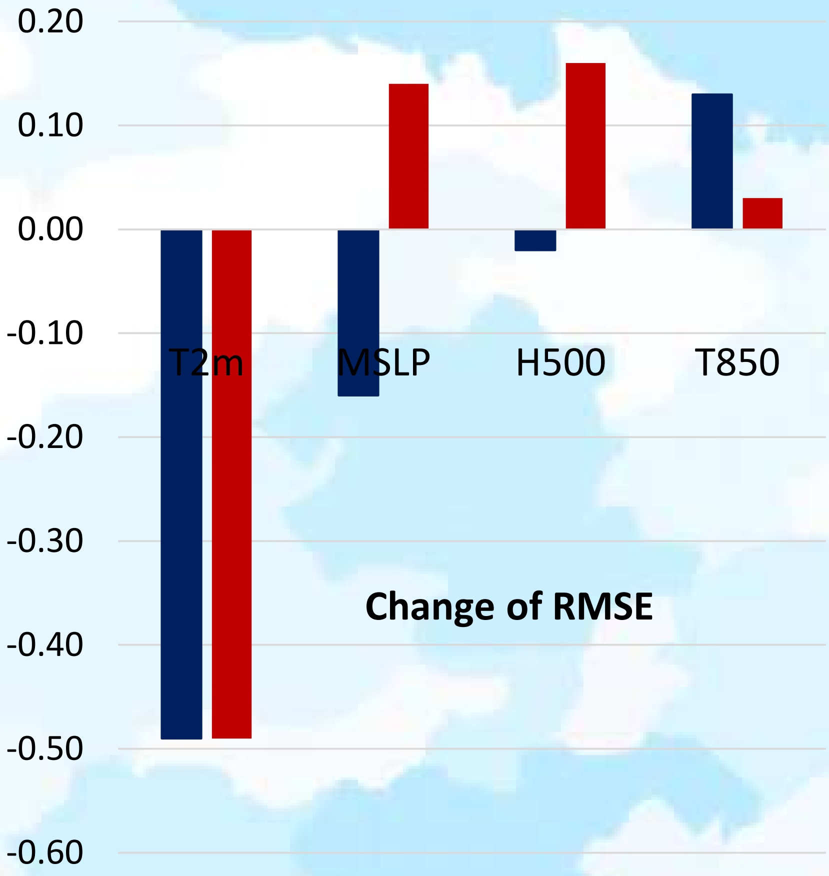
TR: tropics

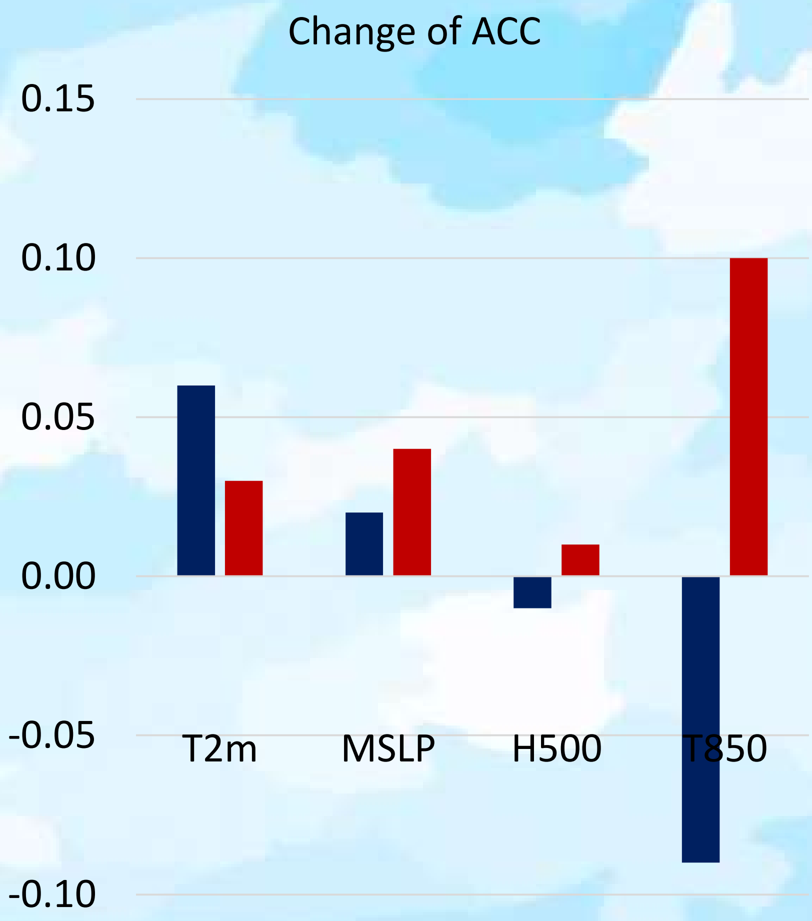
N20 : 20°-90° N

S20: -90°-20° S

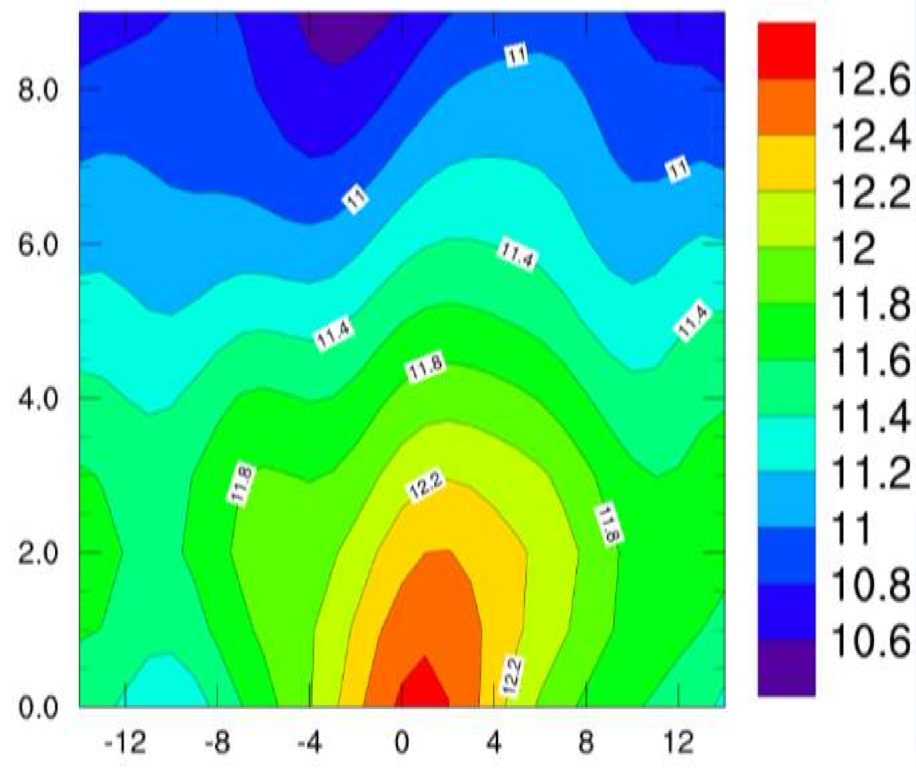


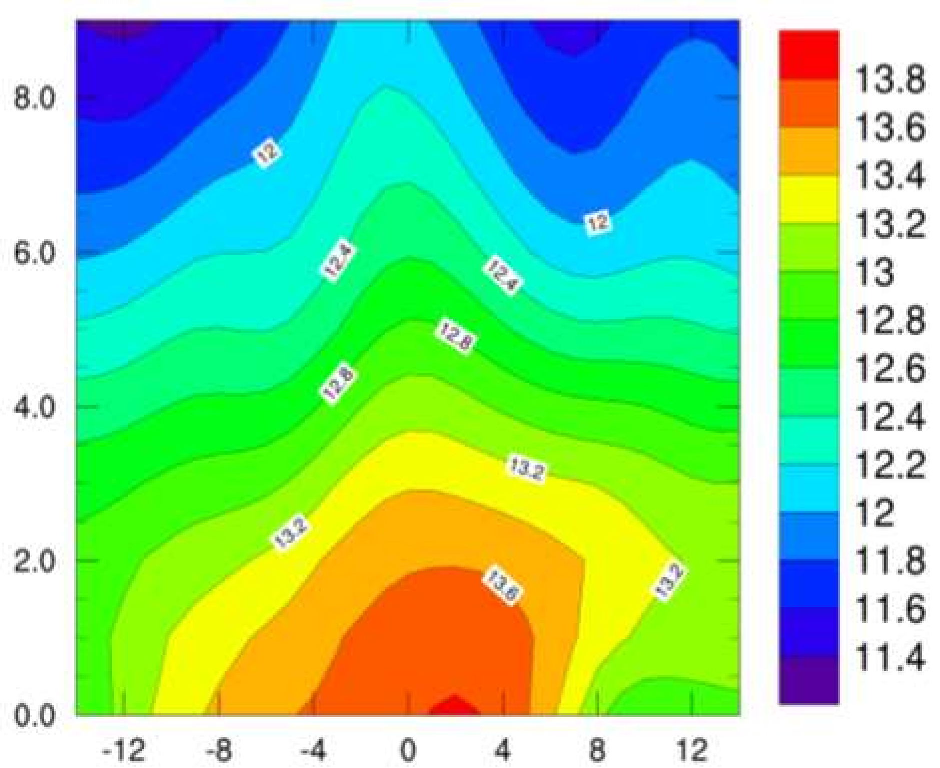
Changes of RMSE and ACC in SL-AV new version operational long-range forecasts: monthly forecast with zero (blue) and 2-weeks lead time (red). CIS region (20-180E, 40-70N), 18 cases





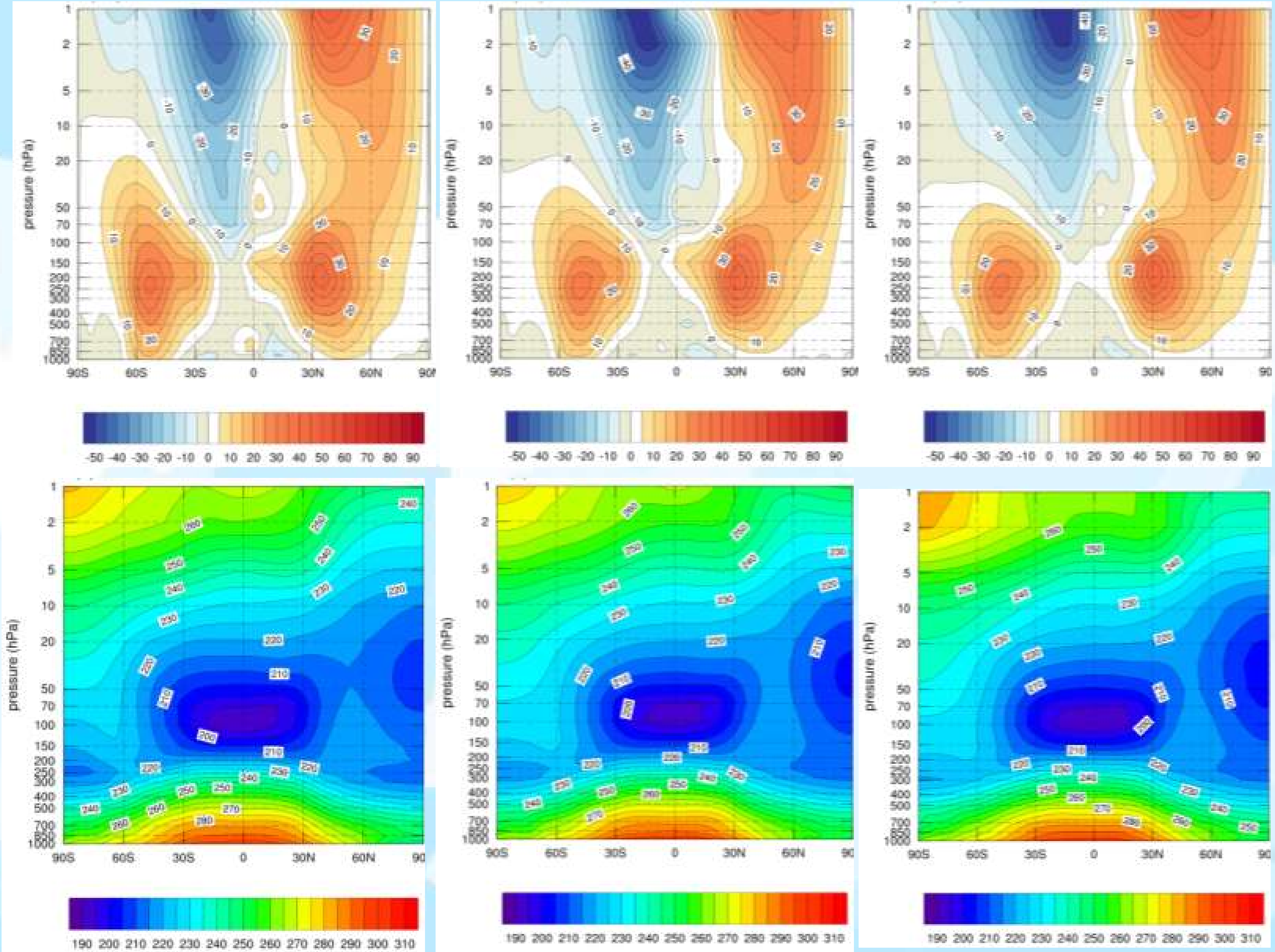
Reproduction of Madden-Julian oscillation





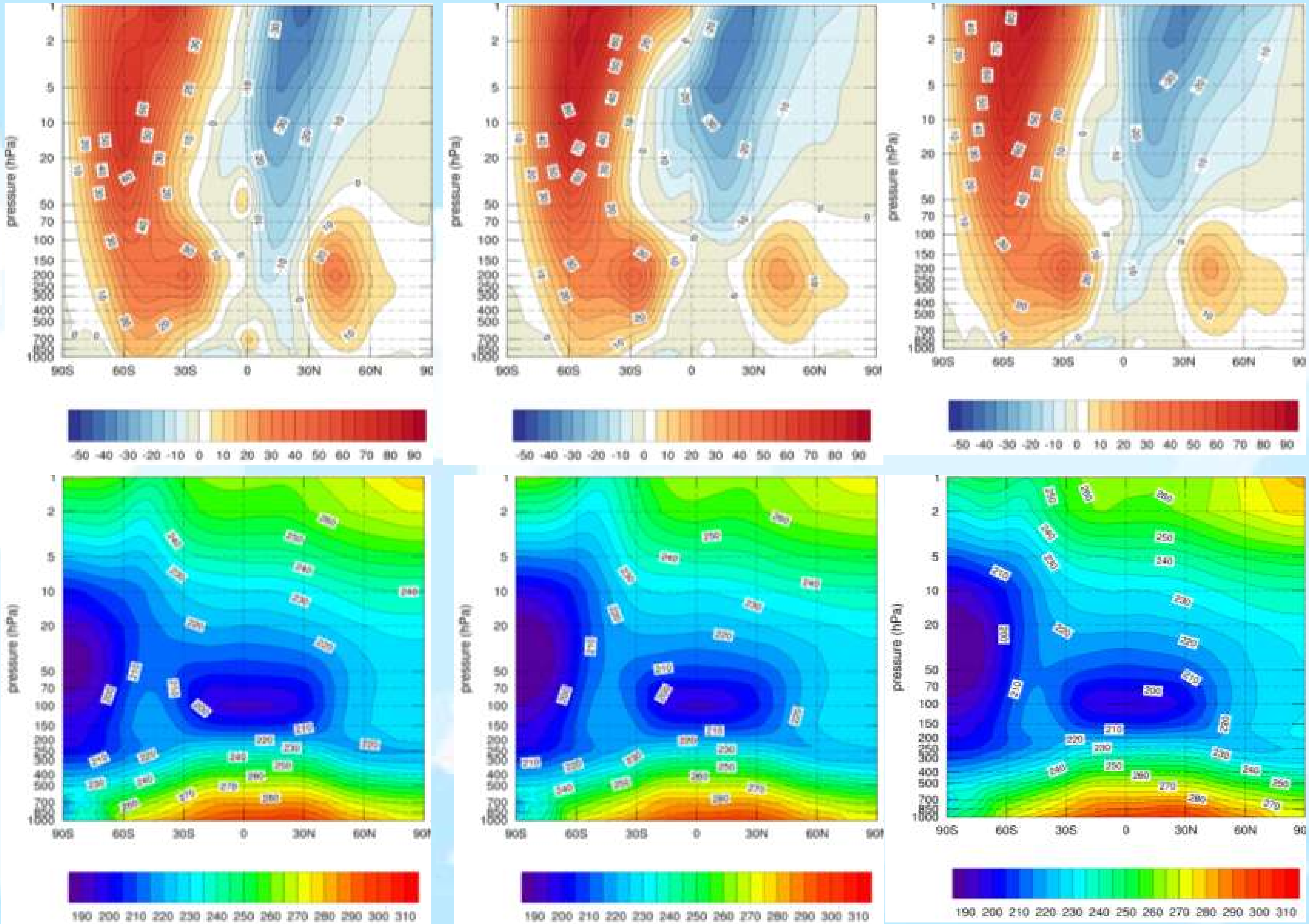
Frequency vs zonal wavenumber. SL-AV model (left), ERA5 reanalysis (right). K=+1 – MJO

SLAV 2018 – 100 lev **SLAV 2022 – 96 yp.** **ERA5**



Zonal mean wind (above) and temperature (below). DJF 1991-2020

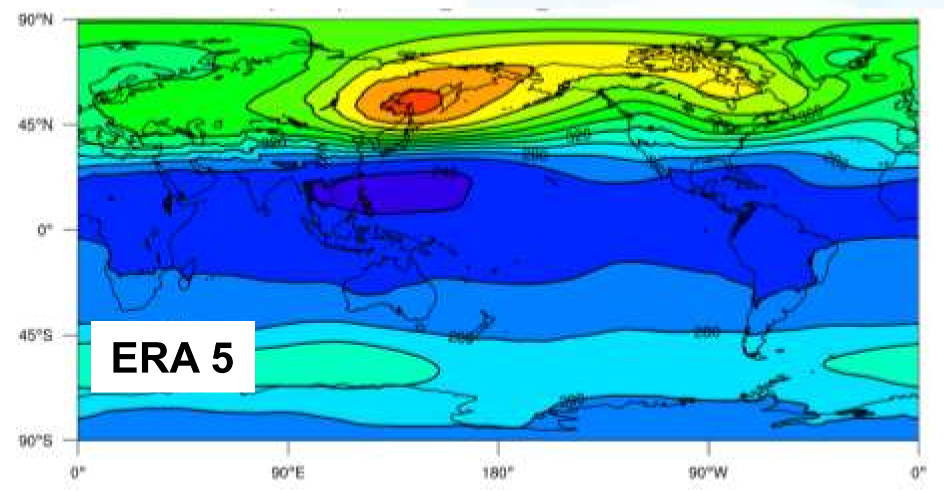
SLAV 2018 – 100 lev **SLAV 2022 – 96 lev** **ERA5**

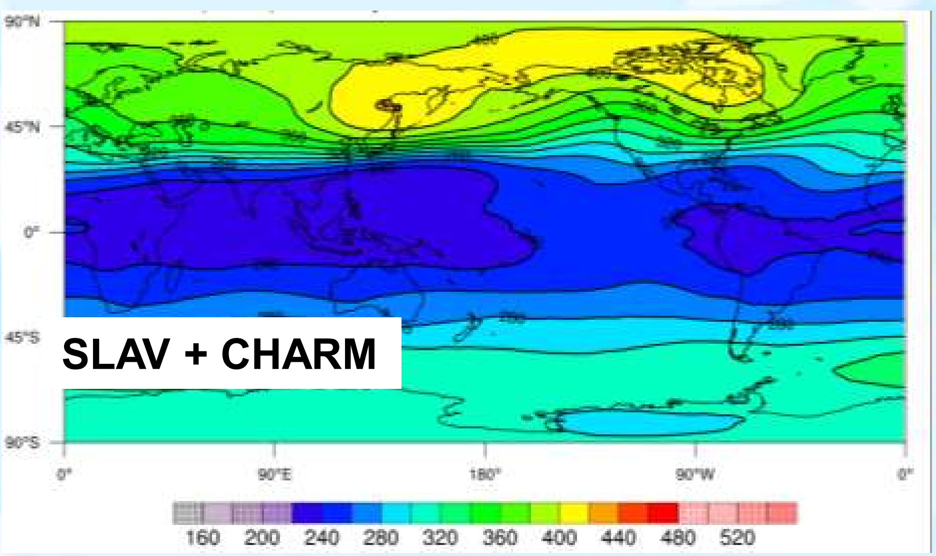


Zonal mean wind (above) and temperature. July-August 1991-2020

Introduction of the photochemical model CHARM (CAO):

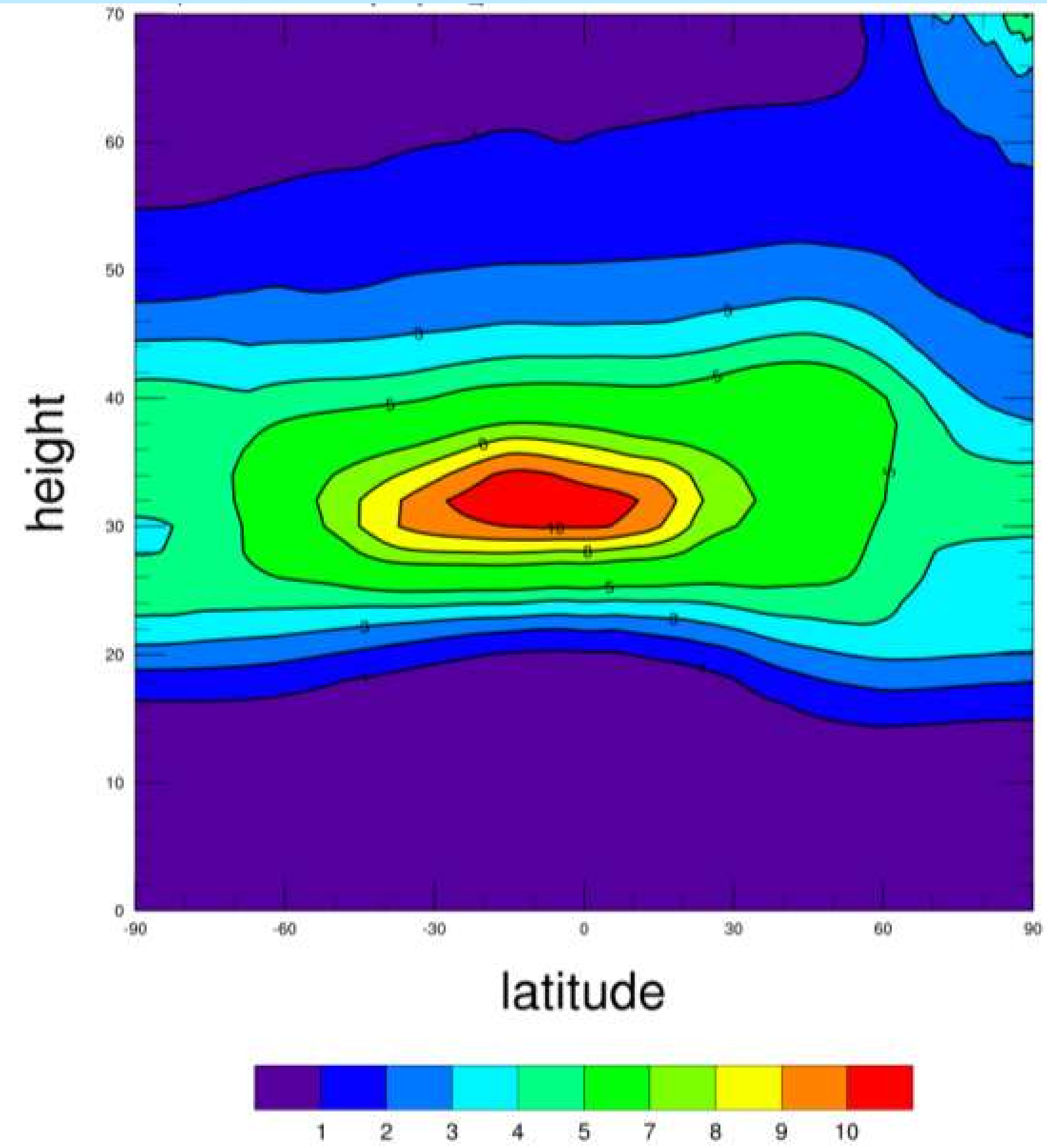
- SLAV horizontal lat-lon (Δx~75 km), CHARM vertical grid (45 levs 0-90 km)
- Mass-conservative, monotone semi-Lagrangian advection CCS3d
- 55 components (Ox, Hx, NOx, CHx, Clx, Brx), chemical families method, non heterogeneous reactions метод химических семейств



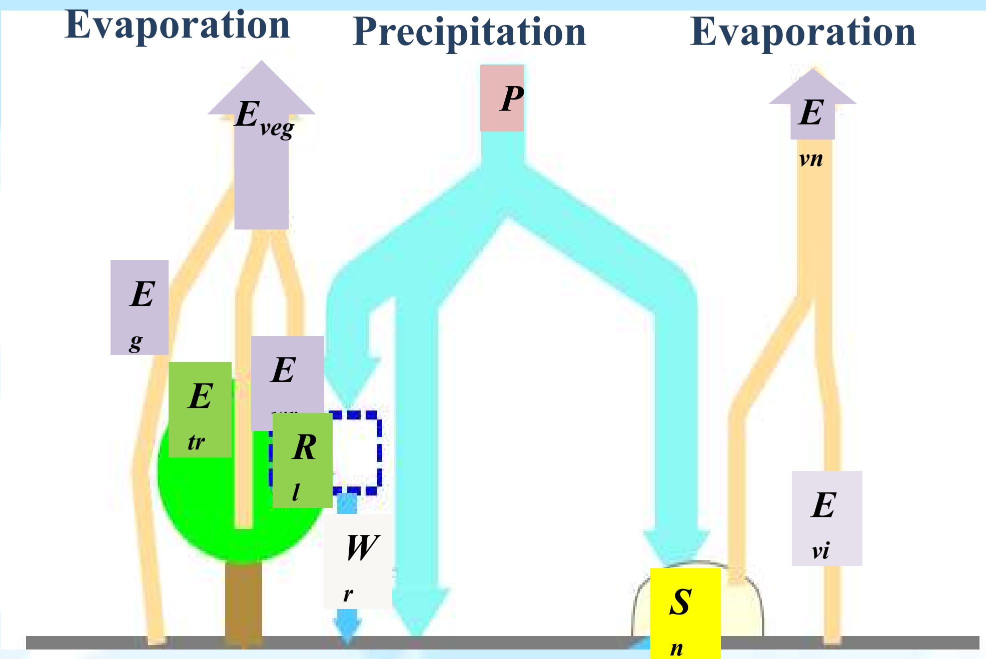


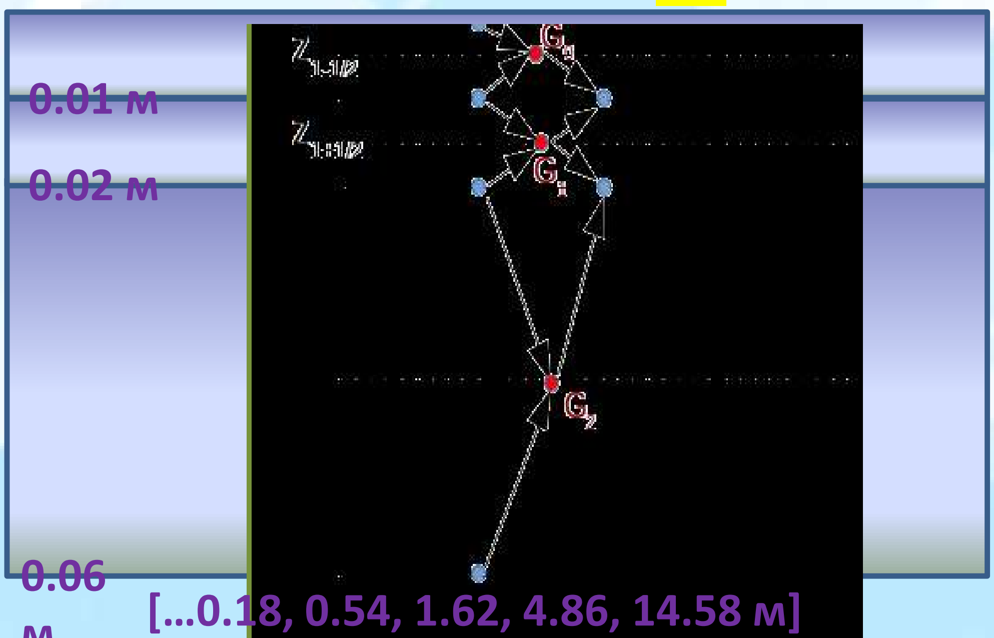
Vertically integrated total ozone concentration (Dobsons). SLAV + CHARM: average for monthly forecasts for Jan 2000-2019. ERA5: average for Jan 2000-2019

Zonal mean ozone concentration (mol/mol). Average for monthly forecasts SLAV+CHARM Jan 2000-2019



Soil-vegetation model





Model equations

[Volodin,Lykossov., 1998]

$$\rho C \frac{\partial T}{\partial t} = \frac{\partial}{\partial z} \lambda \frac{\partial T}{\partial z} + L\rho F_i,$$

$$\frac{\partial W_l}{\partial t} = \frac{\partial}{\partial z} \lambda_l \frac{\partial W_l}{\partial z} + \frac{\partial \gamma}{\partial z} - F_i - R - E_r,$$

Root concentration:

$$R_n = 0.5 \cdot [exp(-\alpha z_{n-1}) + exp(-\beta z_{n-1}) - exp(-\alpha z_{n+1})$$

$T_s, W_{l,s}, W_{i,s}$

$T_1, W_{l,1}, W_{i,1}$

$T_2, W_{l,2}, W_{i,2}$

$T_3, W_{l,3}, W_{i,3}$

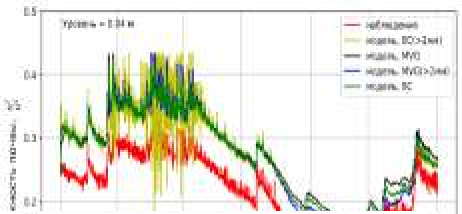
Устьичное сопротивление: $R_s \sim \sum_{n=1}^{9} R_n W_{l,n}$

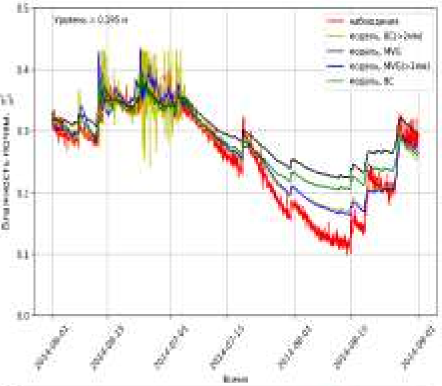
Теплопроводность почвы: $\lambda_n = f(W_{l,n})$

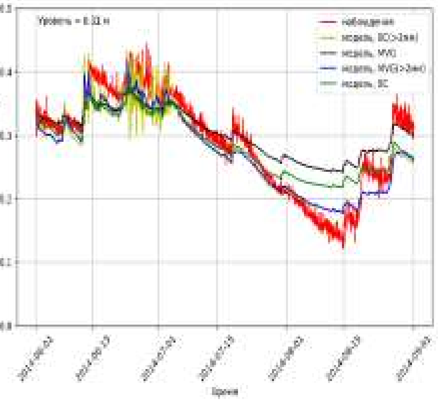
Температура и влажность на уровне поверхности вычисляются по модифицированному алгоритму модели ISBA-2L

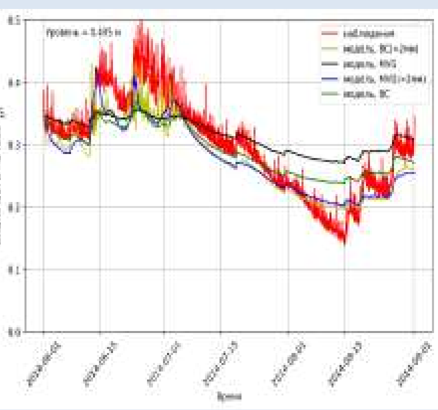
Принципы механизмов влияния влажности почвы глубоких слоев на состояние поверхности остаются такими же, как в ISBA-2L

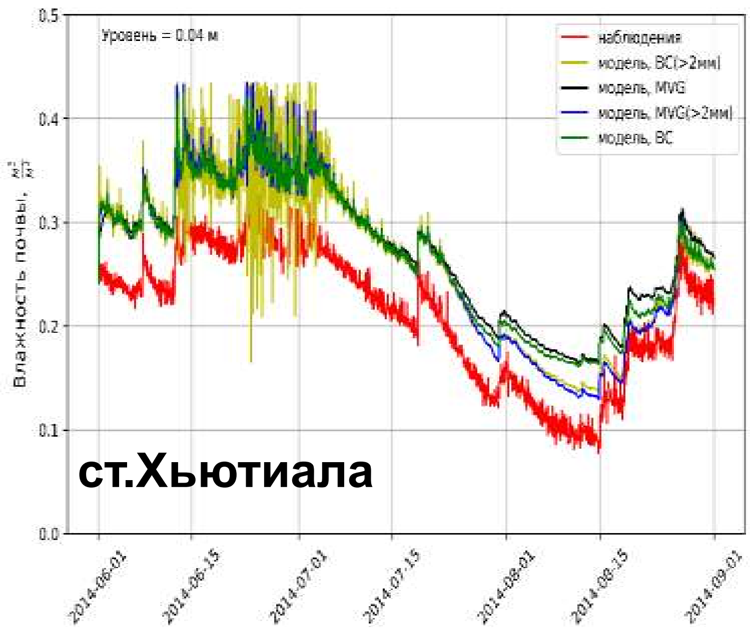
Модель подстилающей поверхности. Влагопроводность

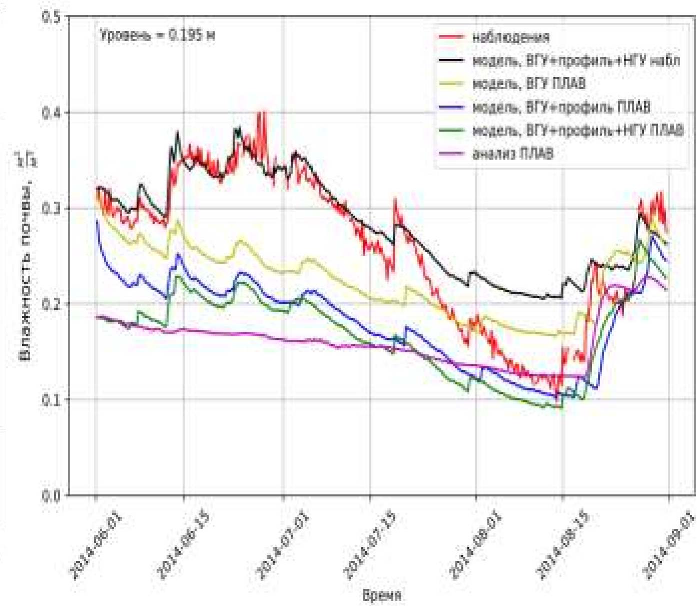


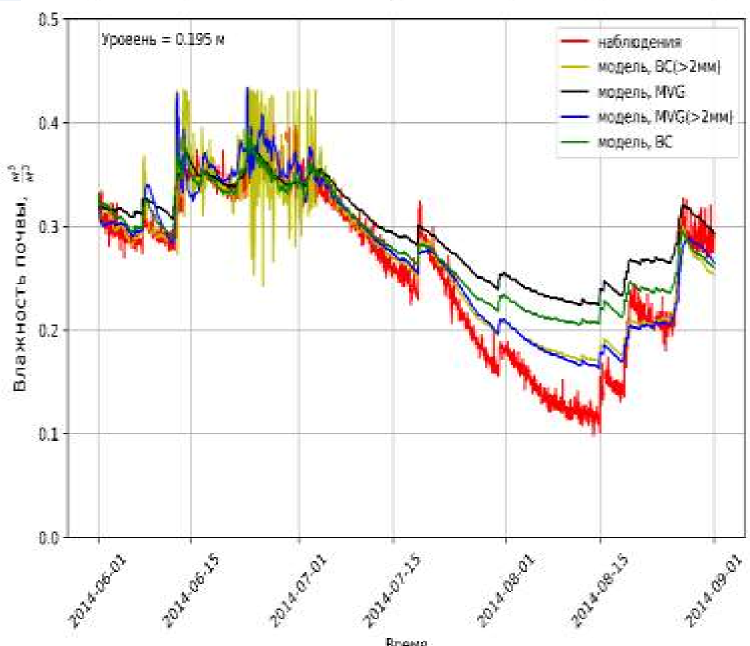


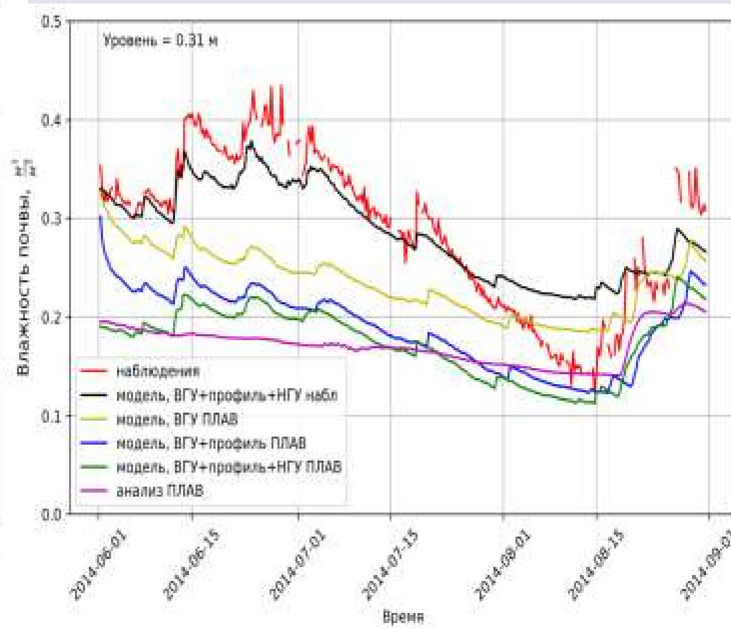




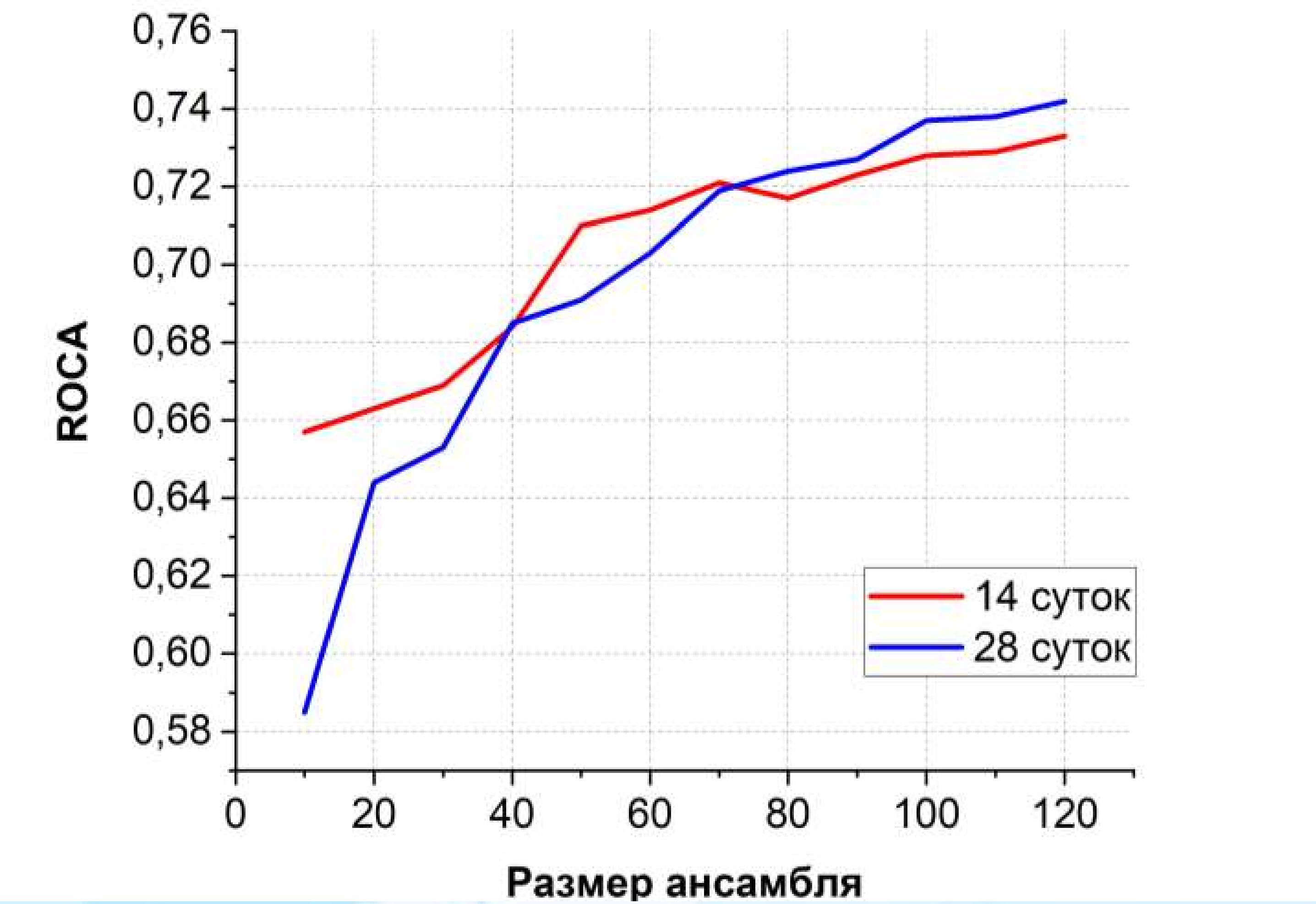








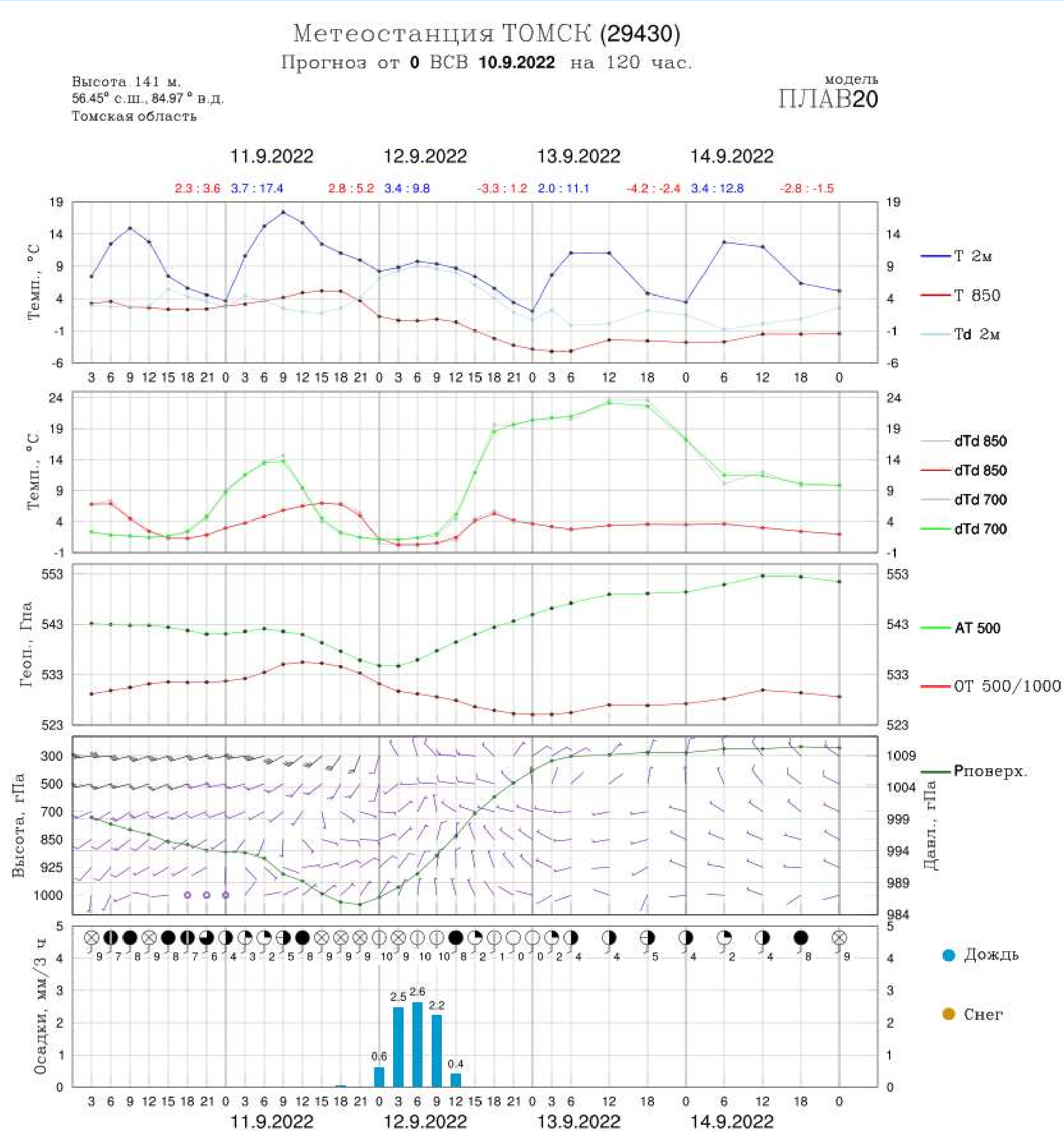
Impact of the ensemble size on forecast estimates



ROC area as a function of ensemble size for predicting positive T850 anomaly greater than 2 standard deviations. Forecasts for 1-14.01.2021, Region: 20˚-90˚ N

Conclusions

- Significant progress in SLAV model subseasonal and seasonal forecasts scores, model climate quality
- Yet many things to be implemented and tuned
- Coupling with the ocean is a key for future progress in SL-AV long-range forecasts



Thank you for attention!

Работы по развитию модели для долгосрочного прогноза выполнены при поддержке гранта РНФ 21-17-00254