Simulation of large-scale atmospheric circulation anomalies at time scales from month to years – current state

Воспроизведение крупномасштабных аномалий атмосферной циркуляции на месяцы и годы - современное состояние

Tolstykh Mikhail (1,2)

Fadeev Rostislav (1,2), Shashkin Vladimir (1,2), Volodin Evgueni (1),

(1) Marchuk Inst. of Numerical Mathematics RAS

(2) Russian Hydrometeorological Research Centre

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*

How is the long-range forecast produced?

- Computation of the multiyear ensemble forecasts starting from the required date to evaluate model climate.
- Computation of the ensemble forecast starting from the required date of the current year.
- Computation of model anomaly with respect to model climate.
- + Statistical postprocessing

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

At seasonal scale: + El Nino- Southern Oscillation

Ocean-atmosphere interaction

The experiments indicate **that short-lived heating produces responses** in midlatitudes at locations **far remote from the source** and these responses persist much longer than the pulses themselves.

Image:

Meridional wind at 300hPa response on 2-day temperature pulse (5°).

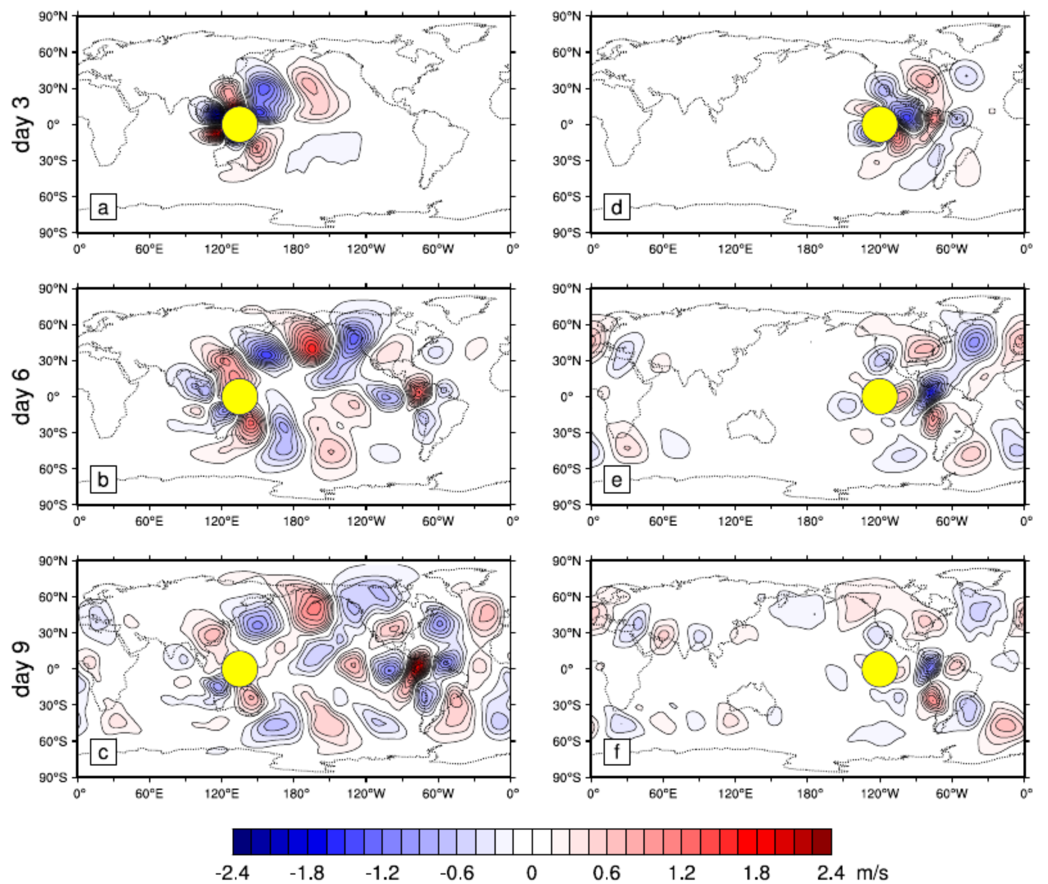


FIG. 3. Ensemble mean $v300$ response in CAM3 to a 2-day pulse of heat at 0°N, 135°E (a) 3, (b) 6, and (c) 9 days after the pulse begins. (d)–(f) As in (a)–(c), but for a pulse at 0°N, 120°W.

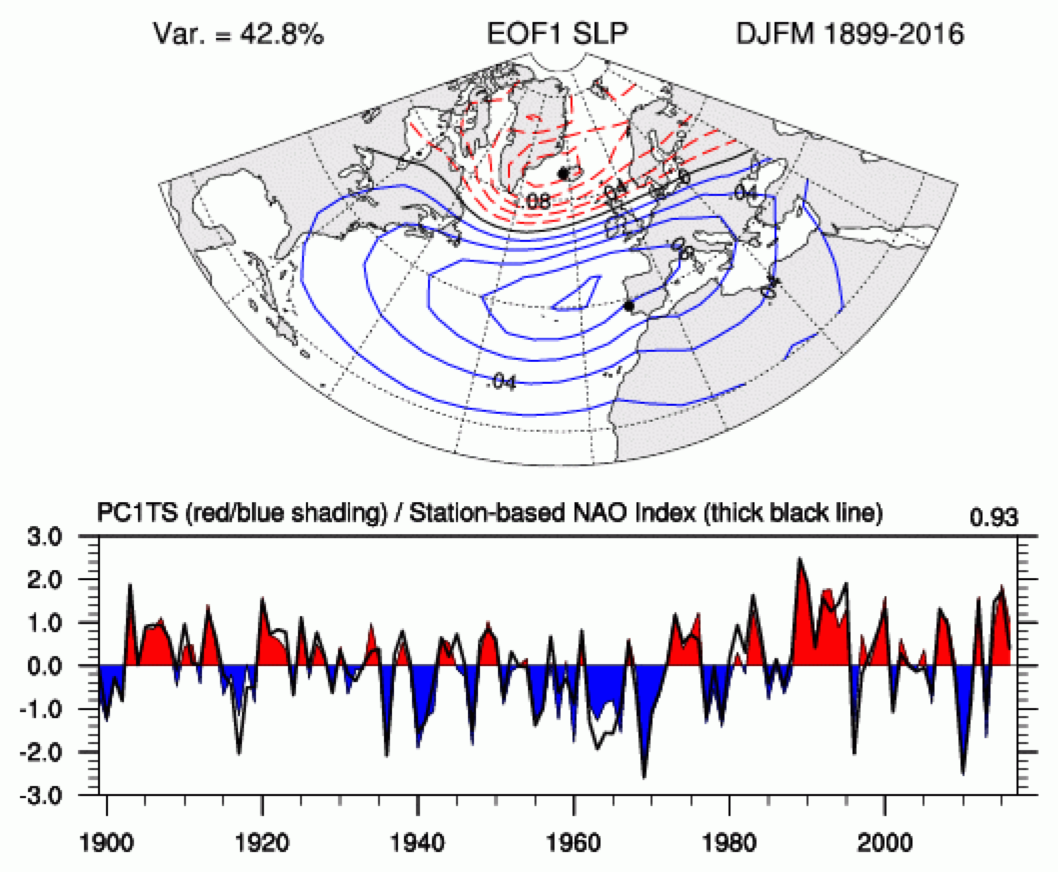
Branstator, J. Climate, 2014;

Sardeshmukh, Hoskins, JAS, 1988.

Subseasonal and seasonal forecasts

- 12 +1 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

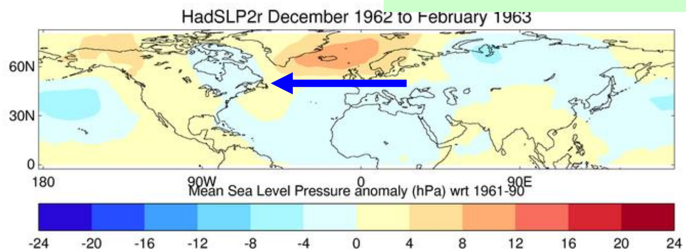
North-Atlantic Oscillation index

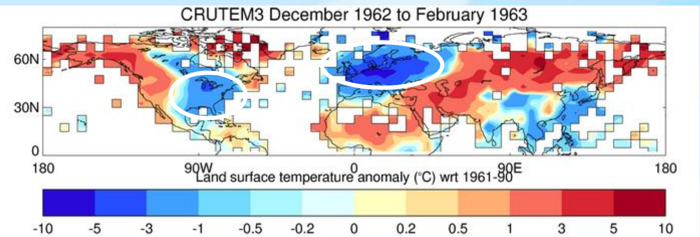


Winter index is relatively predictable by the models !

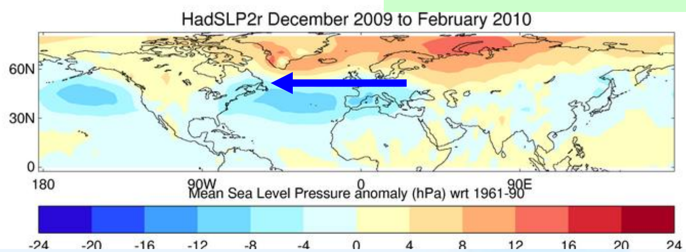
Winters depend on which way the wind blows: The North Atlantic Oscillation (A.Scaife) Kryjov (MiG. 2003, 2004)

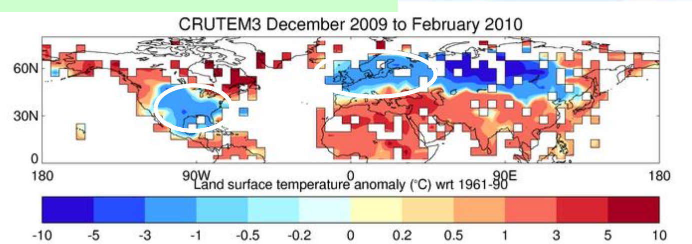
Winter 1962/63





Winter 2009/10



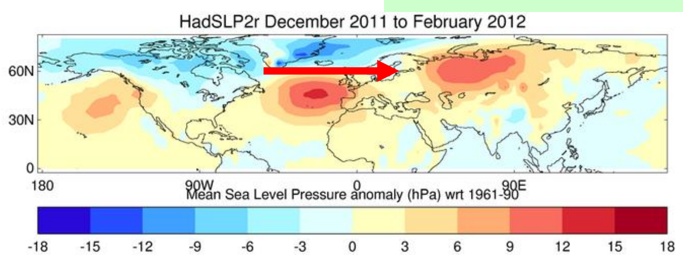


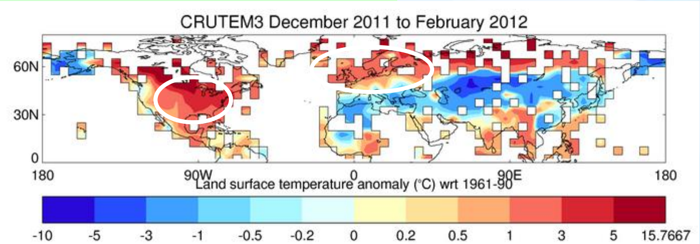
Weak P Gradient

Cold advection into Europe

Cold, calm and dry

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



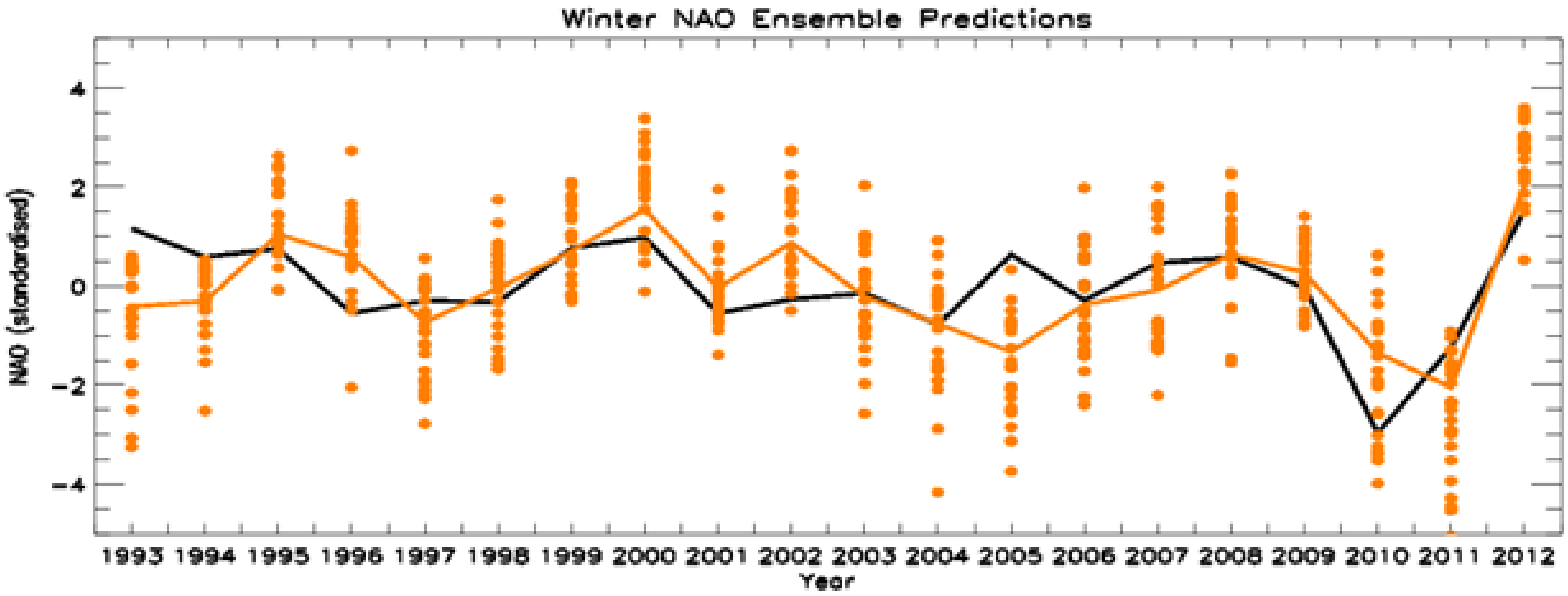


Strong P Gradient

Warm advection into Europe

Mild, stormy and wet

Winter NAO forecasts at theUK MetOffice (A.Scaife)

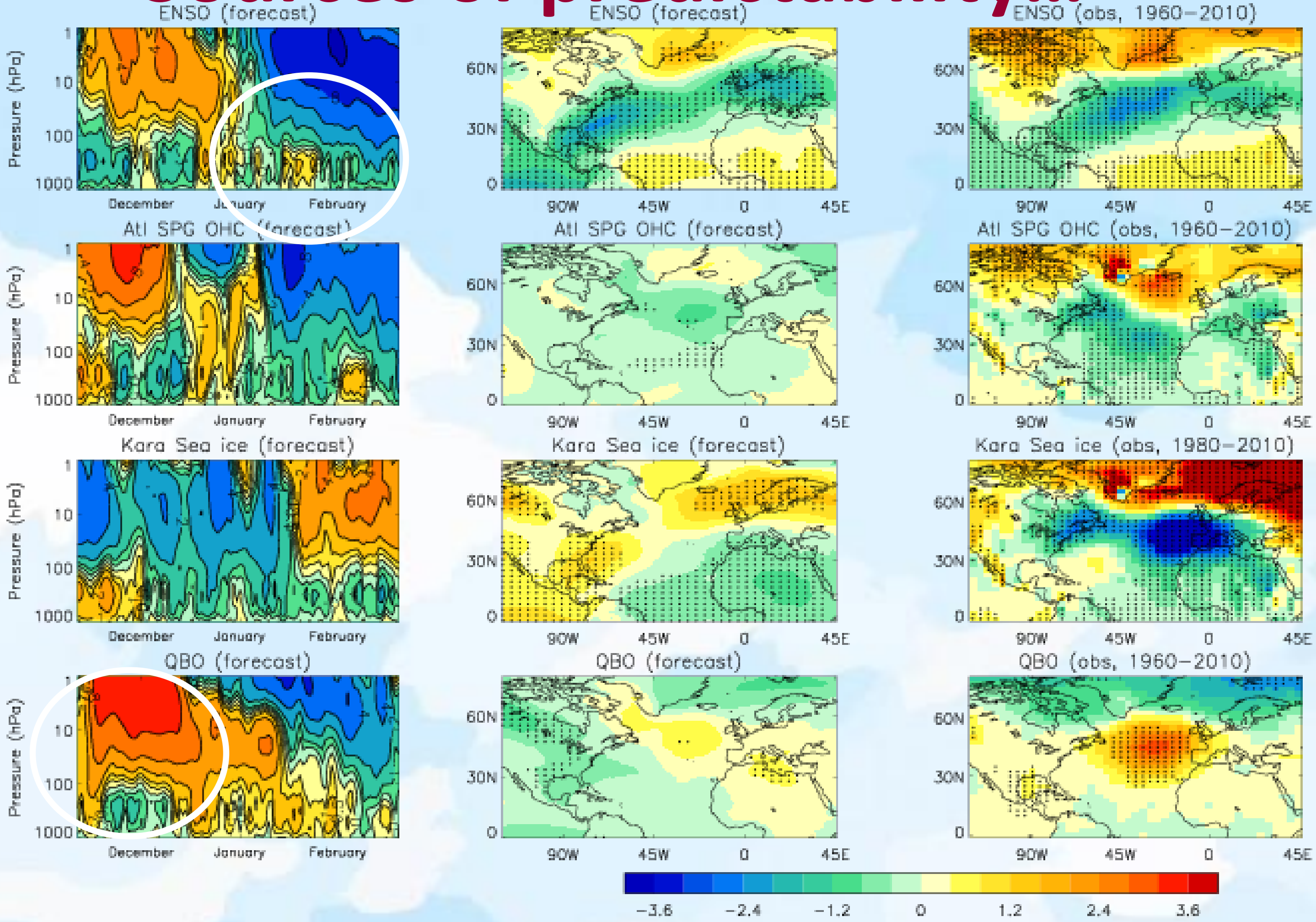


Correlation score = 0.62

Extended to 20 years and 24 members for DJF

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

Sources of predictability…



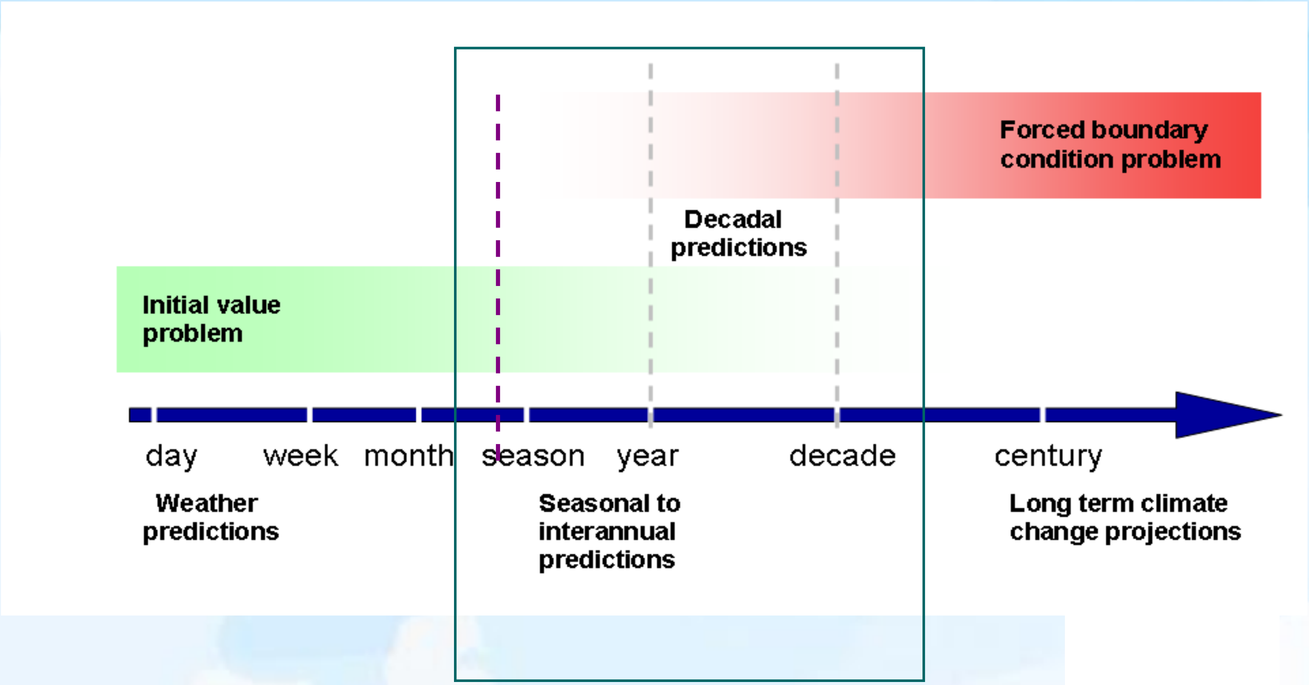
Strongest minus weakest cases for November predictors:
ENSO, Atlantic Ocean, Kara sea-ice and Quasi Biennial Oscillation
Response is weaker in model than obs

Scaife et al 2014

Decadal prediction

- WMO Grand challenge
- CMIP6 subproject
- Using the signal from forcing and boundary conditions changing in time (deep ocean, small gas constituents)
- There is a hope to repeat relative success of seasonal forecasts.
- So far, the quality of interannual forecasts is the same as for seasonal forecasts more than 10 years ago.

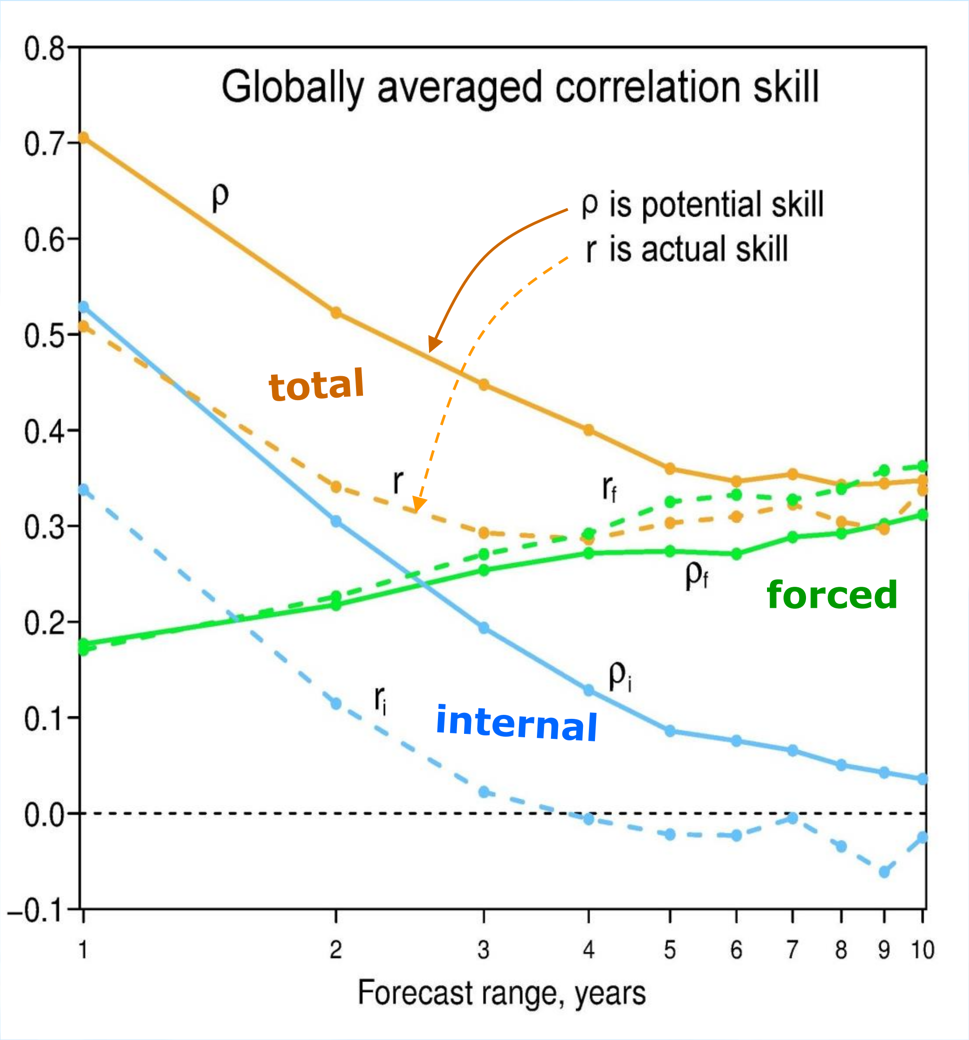
Where does a decadal prediction fit? (G.Boer)



Decadal prediction:

- **annual, multi-annual, up to a decade**
- **initialized forecasts of both forced and internally generated components of variability**

Prediction and skill of annual mean T



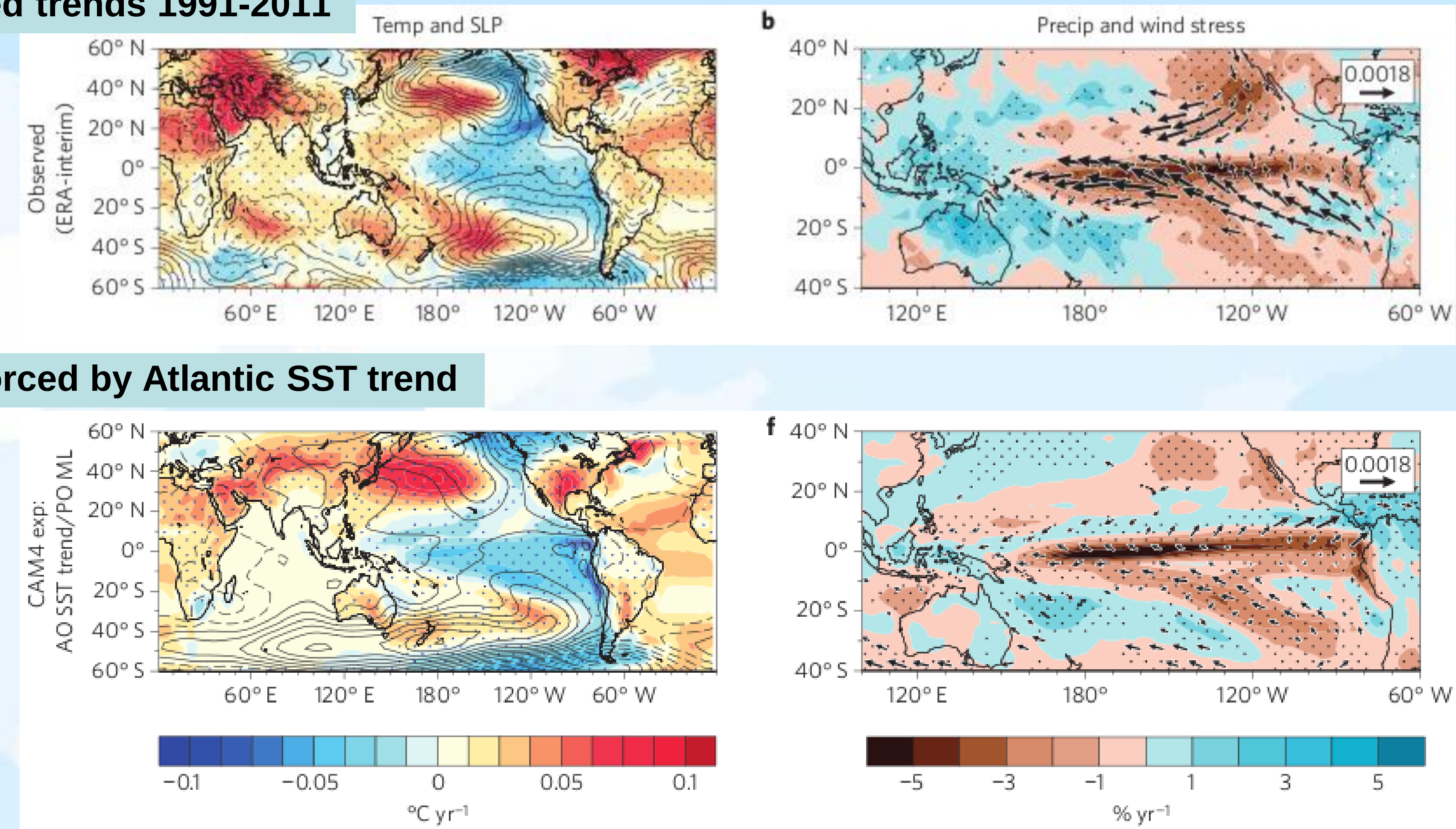
Boer et al. (2013)

- global and local "predictability" and "skill"
- mechanisms determining skill
  - importance of initialization vs external forcing
  - deep ocean processes
  - etc.
- predictability and skill as a function of forecast range - difference between ρ and r may offer:
  - guidance on mechanisms
  - hope for improvement

Atlantic driving the Pacific?

Observed trends 1991-2011

Model forced by Atlantic SST trend



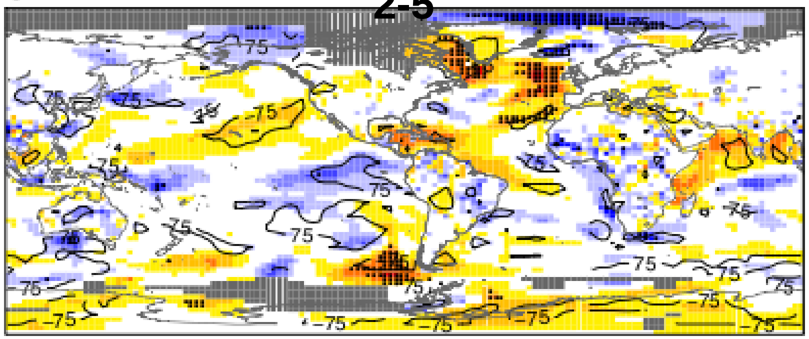
- **Increase in Pacific trade wind is simulated by model driven by observed Atlantic SST trend**

➢ **Potential key role of North Atlantic warming**

McGregor et al 2014

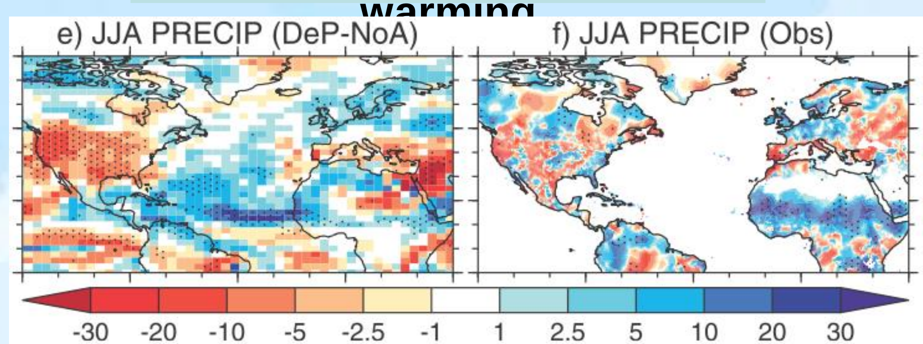
Atlantic SPG and decadal predictions

Impact of initialization on skill yrs 2-5



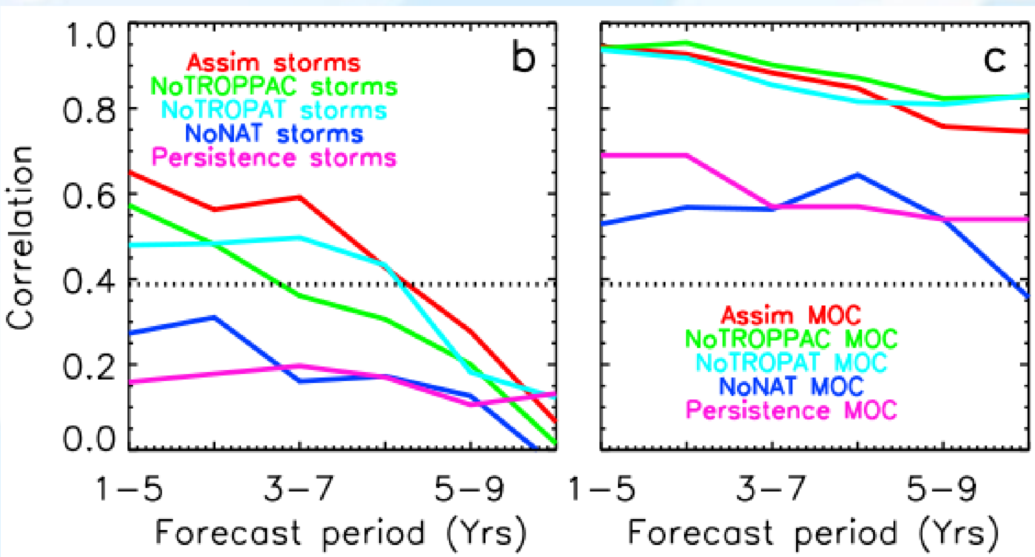
Doblas-Reyes et al 2013

JJA rainfall change associated with 1995 SPG warming



Robson et al 2013

Perfect model skill of Atlantic tropical storms and AMOC : no skill when SPG initialized with climatology (blue curves)



Dunstone et al 2011

- **North Atlantic SPG is the region showing most improved skill from initialization**
- **Potentially influences rainfall over Sahel, USA, Europe, Amazon**
- **Influences Atlantic tropical storms and AMOC in perfect model experiments**
- **Motivates further experiments to understand processes**
- **Repeat hindcasts but initialize SPG with climatology**

SL-AV global atmosphere model (1)

SL-AV: **S**emi-**L**agrangian, based on **A**bsolute **V**orticity equation

- **Finite-difference semi-implicit semi-Lagrangian** dynamical core of own development. Vorticity-divergence formulation, unstaggered grid (Z grid), 4th order finite differences
- Possibility to use **reduced lat-lon grid** in dynamical core. (Tolstykh, Shashkin JCP 2012; Shashkin, Fadeev Tolstykh, JCP 2016;Tolstykh, ShashkinTolstykh et.al., Geosci.Mod.Dev., 2017).
- **Mass-conserving version** (Shashkin, Tolstykh GMD 2014)
-

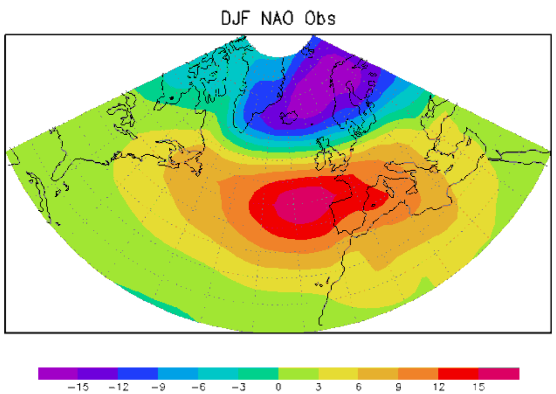
SL-AV global atmosphere model

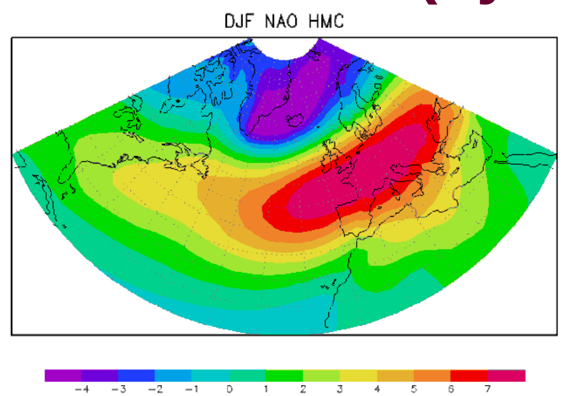
- Many parameterizations algorithms for subgrid-scale processes developed by ALADIN/ALARO consortium.
- Parameterizations for shortwave and longwave radiation: CLIRAD SW + RRTMG LW.
- INM RAS- SRCC MSU multilayer soil model (Volodin, Lykossov, Izv. RAN 1998).
- Marine stratocumulus parameterization

Current applications of SL-AV model:

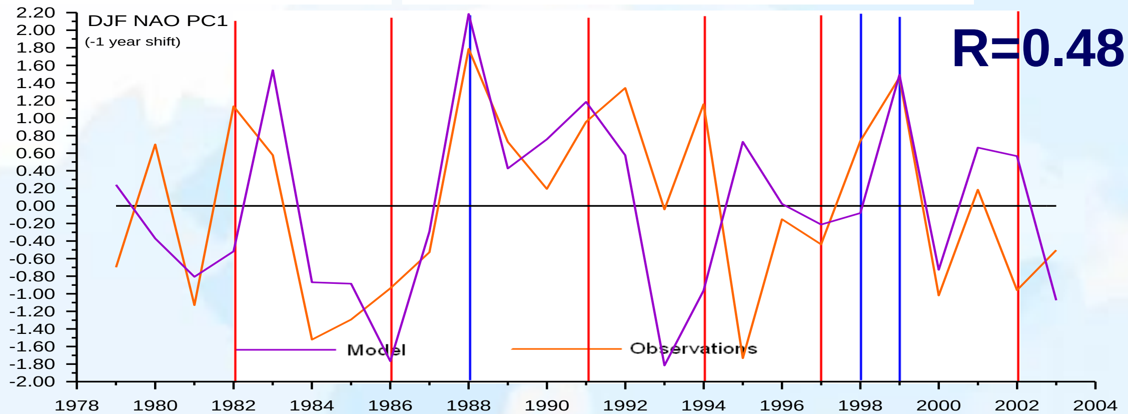
- Operational medium-range weather prediction up to 10 days; probabilistic seasonal forecast at Hydrometcentre of Russia.
- Weather prediction up to 3 days at Novosibirsk.
- 60 days weekly forecast (S2S Prediction project, WMO) – quite old SL-AV version ! Need of urgent update

Predictions of the DJF mean NAO index with the seasonal version of SLAV model (by V.N.Kryjov) -2012



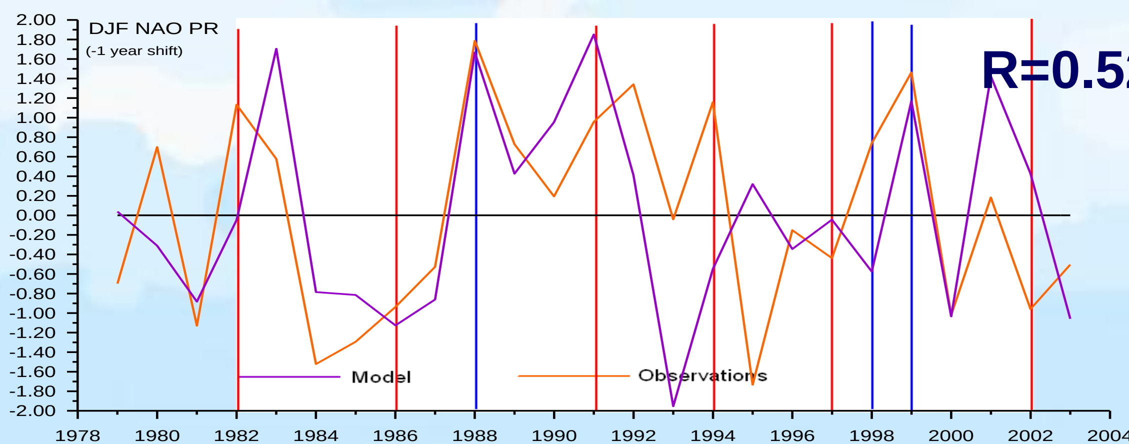


EOF1 of wintertime (DJF) SLP over the North Atlantic in observations (left) and model predictions (right)



R=0.48

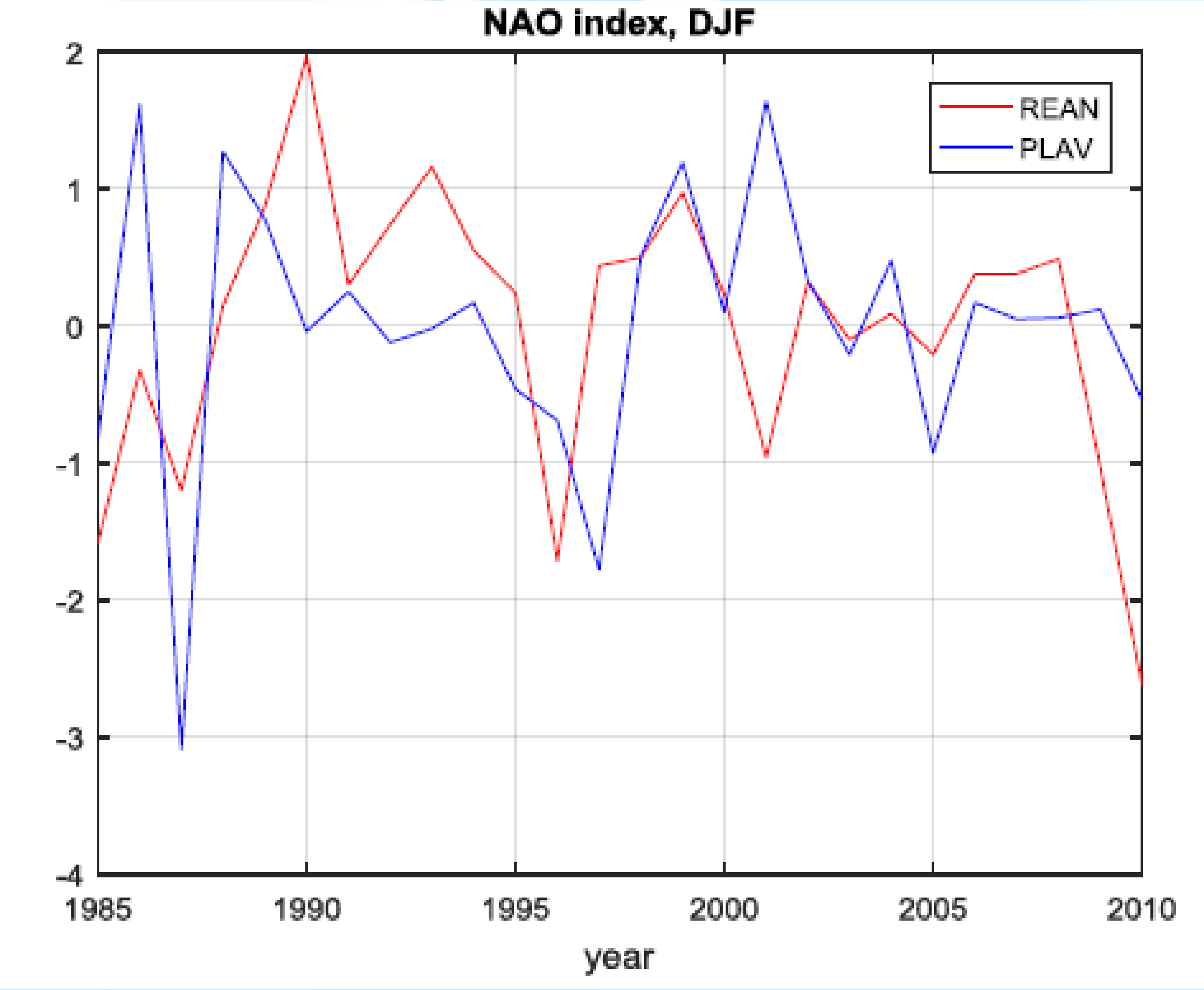
Time series of the DJF mean NAO index in observations (PC1o, orange) and in model predictions (violet) as PC1m (middle) and as PR (bottom).



R=0.52

Blue/red vertical lines denote the winters of La-Nina/El-Nino, to which predictions appear not sensitive

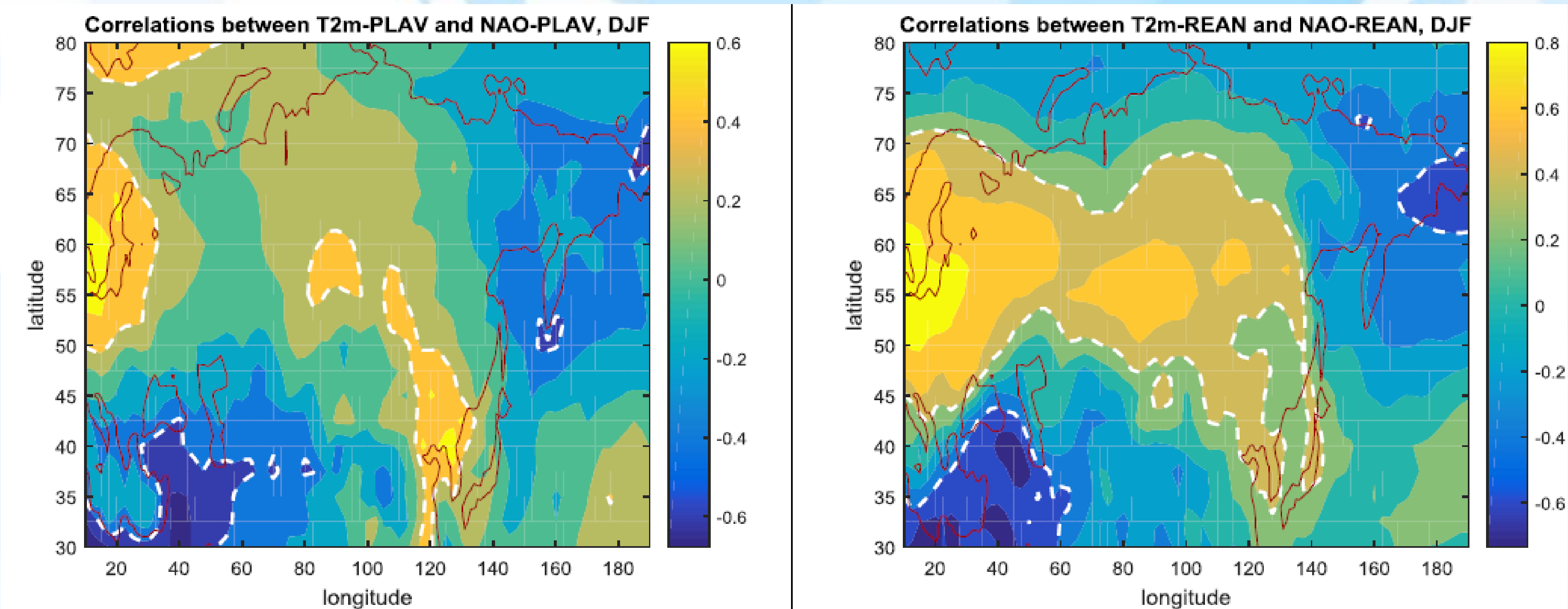
Old seasonal SL-AV version: reproduction of NAO index



- Correlation: 0.3
- Currently, best models (UKMO) have 0.62

Courtesy of V. Khan

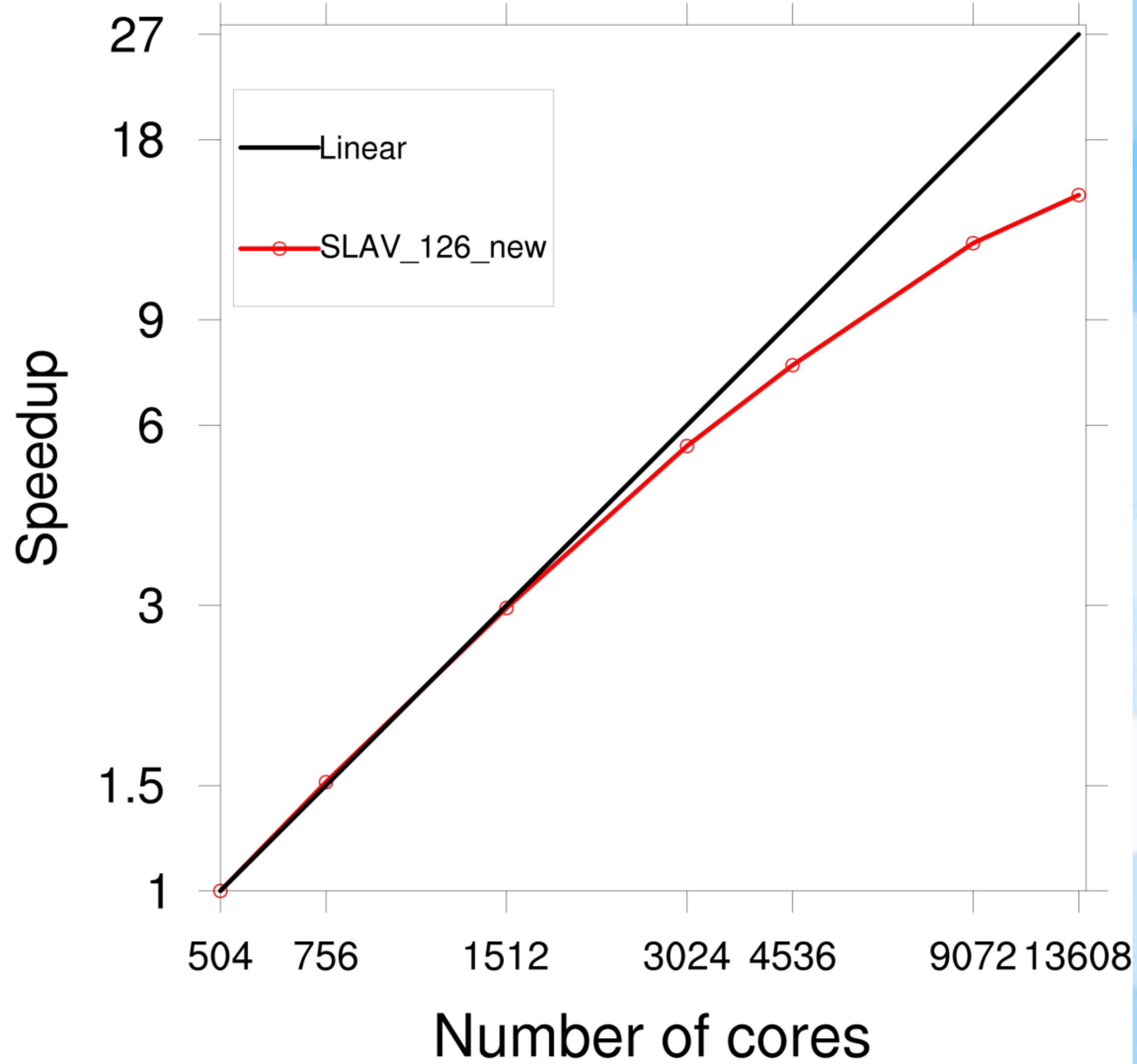
Correlations of winter NAO index and T2m: old SL-AV model (left) and NCEP/NCAR2 reanalysis (right)



Courtesy of V.Khan

Making NAO forecast better would provide practically useful winter T2m seasonal forecast over significant part of Russia

SL-AV code parallel speedup at Cray XC40 w.r.t to 504 cores



Horizontal grid of 3024x1513 points (~13 km). 126 vertical levels

Tasks for making SL-AV model suitable for long range forecasts

- description of stratosphere processes

(Scaiffe et al GRL 2005)

- better description of 'boundary layer – convection-cloudiness' complex

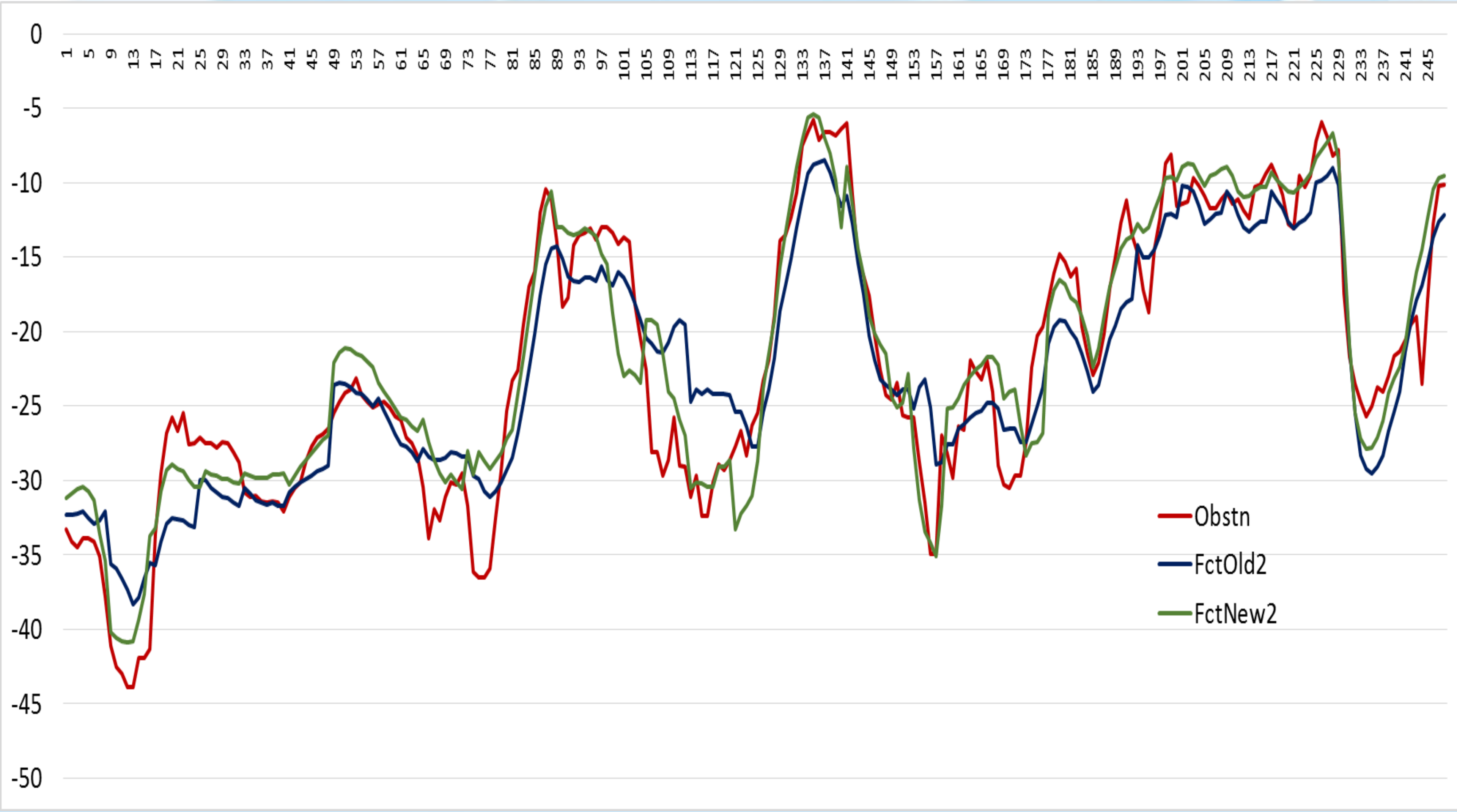
SL-AV model developments in 2017 (1)

- Modernized deep convection parameterization
- New shallow convection parameterization.
- Modified cloudiness and microphysics parameterizations.
- New boundary layer parameterization algorithm *(Bastak-Duran,Geleyn,Vana, JAS 2014)*

SL-AV model developments in 2017 (2)

- 1. The 85-level grid (0.3 hPa) (from 100 to 10 hPa – mesh size of 500 to 700 m, upper – increase to 1 km).
- 2. Finite-element scheme for hydrostatics equation
- 3. Incorporation of convective gravity-wave drag parameterization (Hines 97) as implemented in INM RAS model.
- 4. Tuning of p. 1 -3

T2m **observations** (˚C) at station 23631 (65,05˚ E, 63,93˚ N) (**red line**) for Jan. 2015 (step 3hrs; X axe – # of step), SL-AV forecasts at this point: **old** parameterization (**blue**), **new** parameterization (**green**). Concatenated 6-27hrs forecasts from each day.

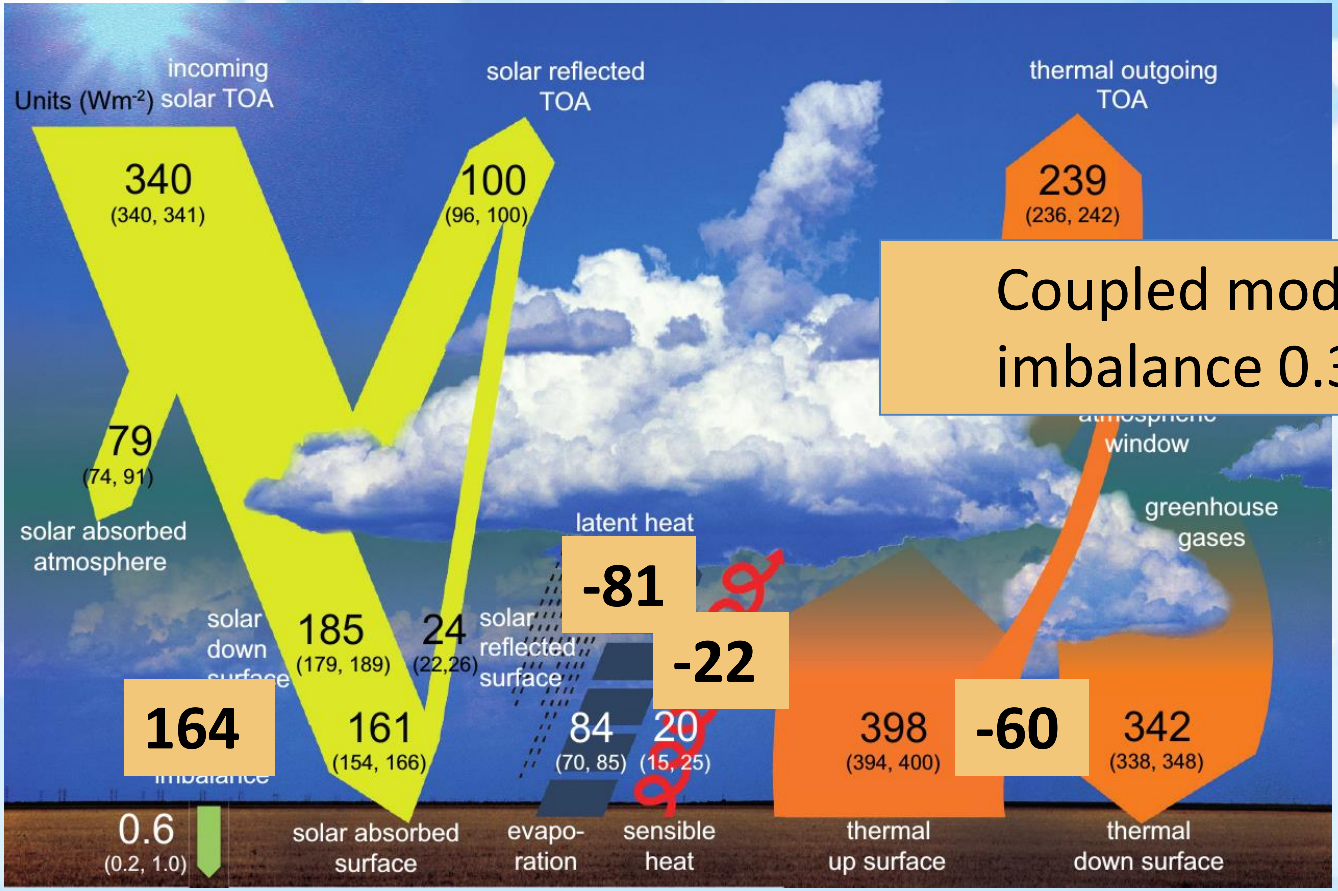


T2m abs. error comparison

	Europe 12	Europe 24	Siberia 12	Siberia 24	Asia 12	Asia 24
OLD	2.69	2.48	4.13	3.56	3.78	3.36
NEW	2.61	2.32	3.93	3.07	3.35	2.96

Global mean energy budget (W/m²)

The genesis and evolution of Earth's climate is largely regulated by the global energy balance and its spatial and temporal variations.

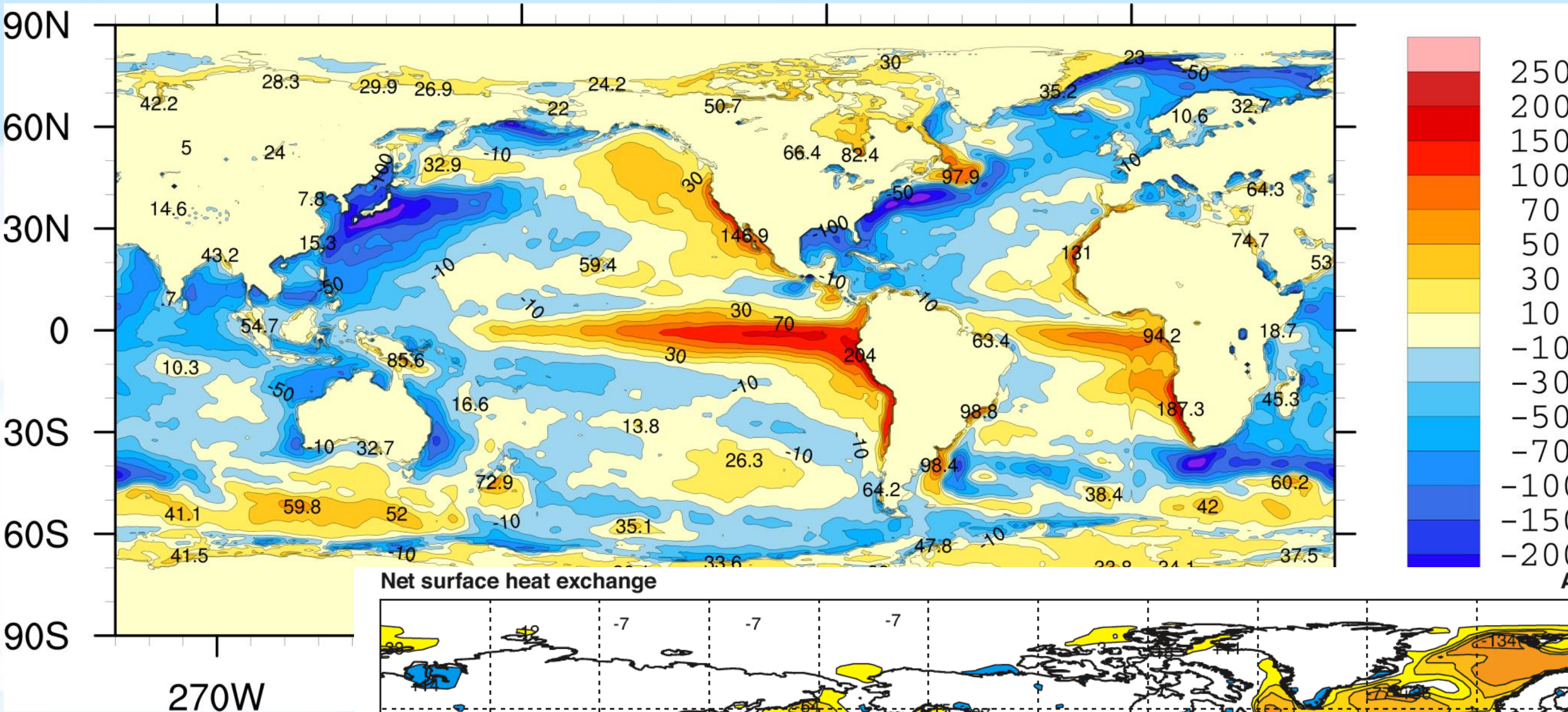


IPCC Fifth Assessment Report (AR5). Climate Change 2013: The Physical Science Basis // http://www.ipcc.ch/report/ar5/wg1. Wild et al, CM, 2013.

Global mean energy budget (W/m^2) in the coupled model

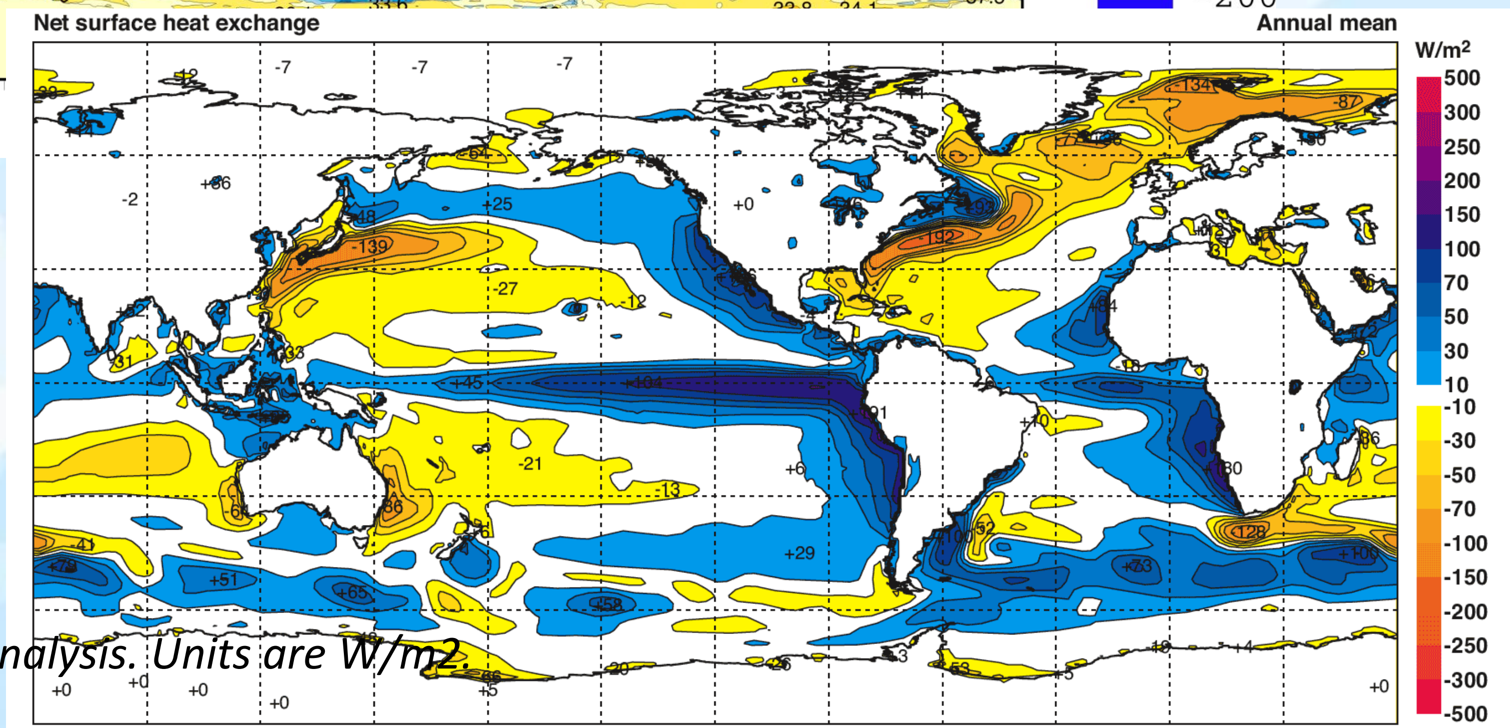
item	IPCC data (range, absolute values), W/m^2	IPCC data (recommended values), W/m^2	Prescribed ocean experiment, W/m^2	Coupled model experiment, W/m^2
Top incoming short-wave radiation	340-:-341	341.3	341.6	341.6
Top outgoing short-wave radiation	96-:-100	100	109.3	107.1
Top outgoing long-wave radiation	-(236-:-242)	-239	-232.4	-234.6
Surface downward solar radiation	154-:-166	161	163.7	164,3
Surface long-wave radiation balance	-(54-:-58)	-56	-60.0	-60.7
Surface sensible heat flux	-(15-:-25)	-20	-22.3	-22.1
Surface latent heat flux	-(70-:-85)	-84	-82.1	-81.2
Imbalance	**-**	**1**	**0.1**	**0.3**

Annual mean surface heat flux



SL-AV2015

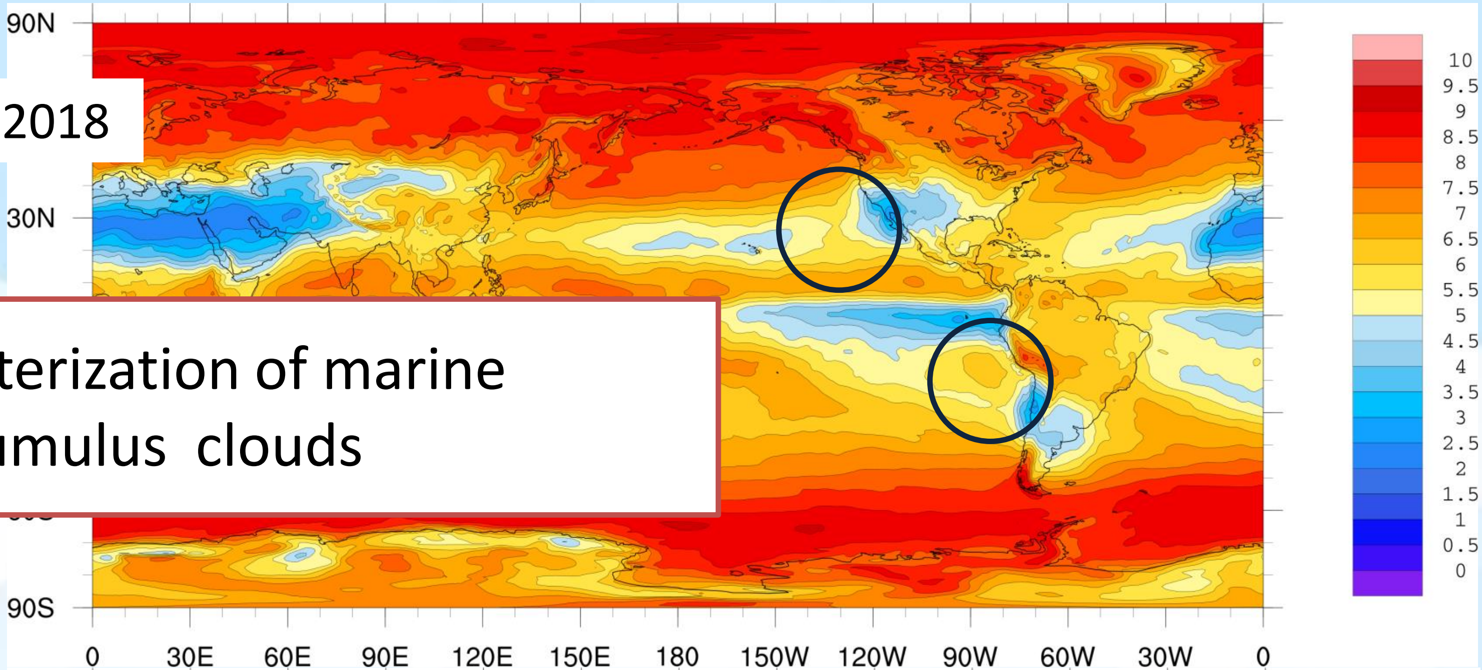
28 levs



ECMWF 40-year reanalysis. Units are W/m2.
Kallberg et al 2005.

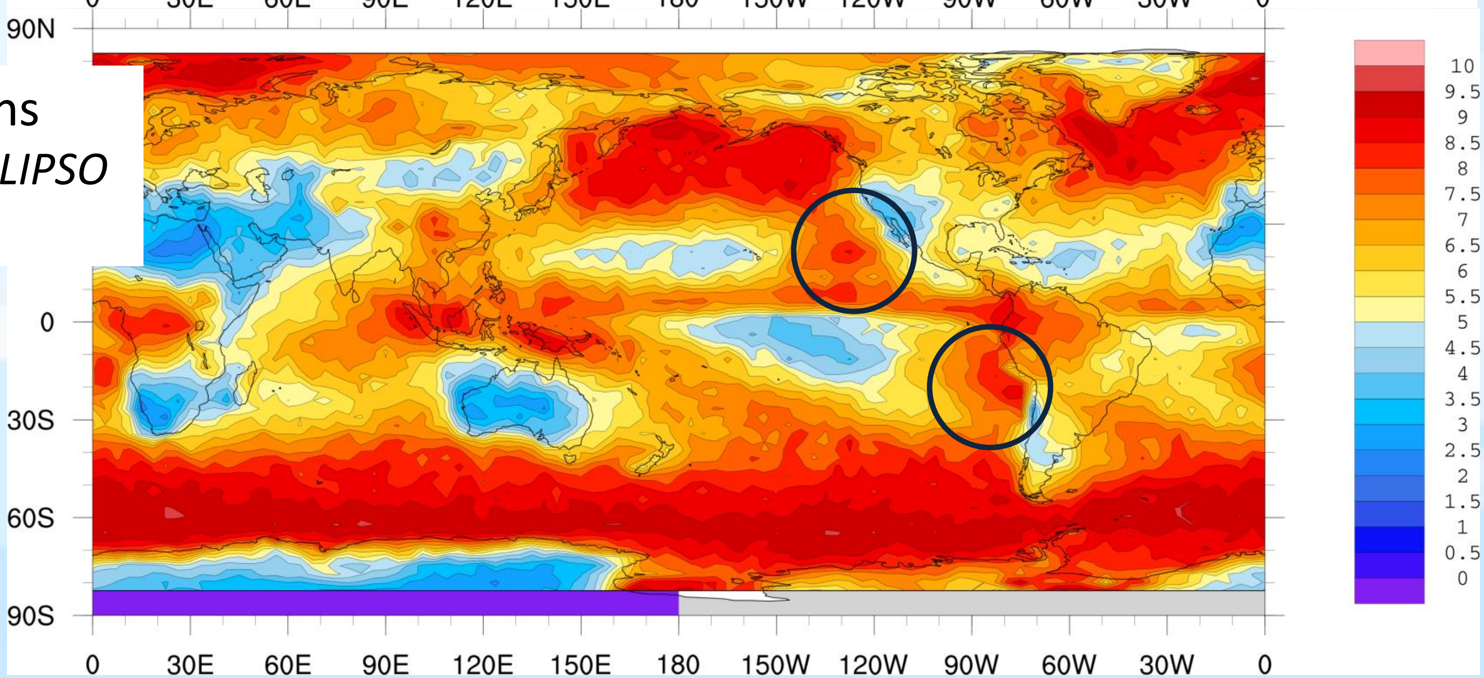
Annual mean cloudiness

Slav, 85 lvl, 2018

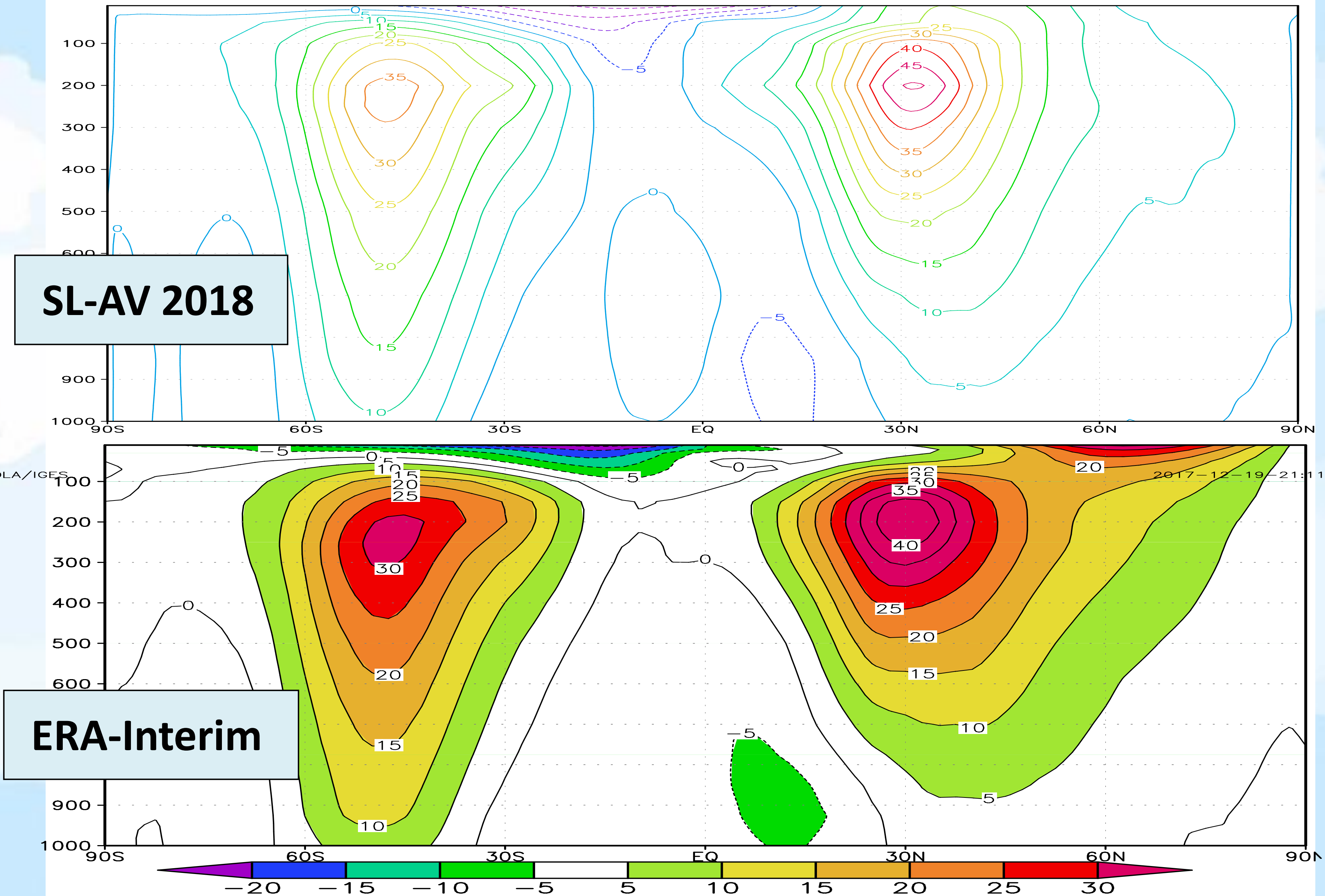


Parameterization of marine srtatocumulus clouds

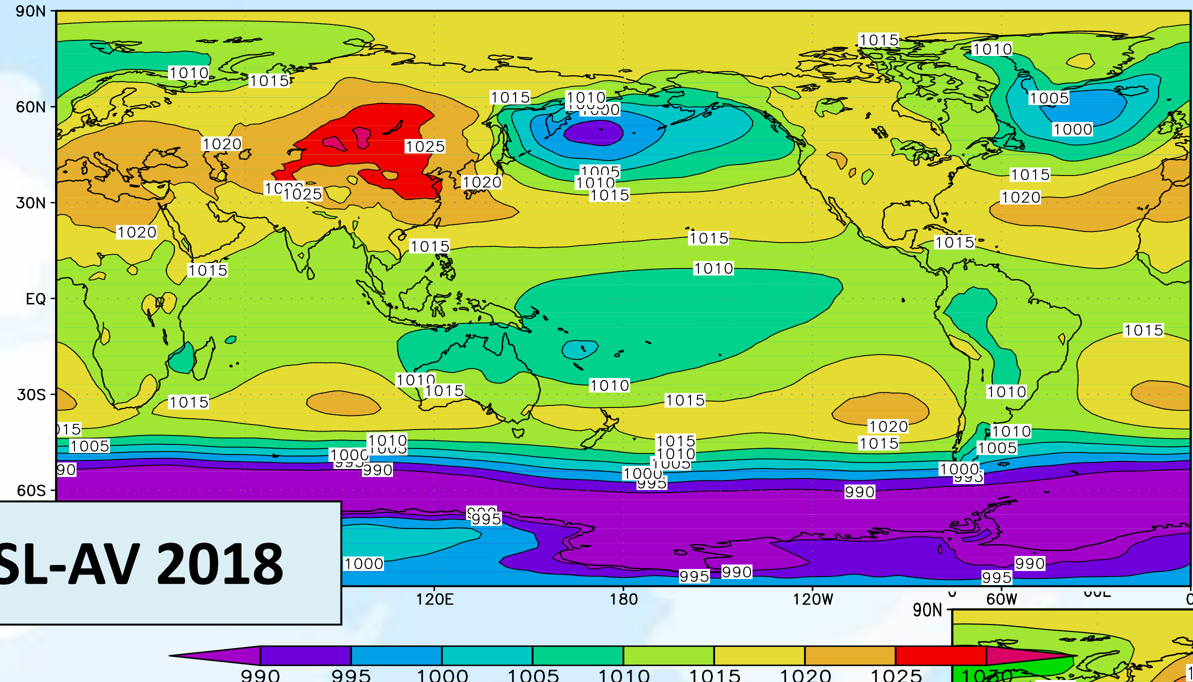
Observations
CloudSat/CALIPSO Data



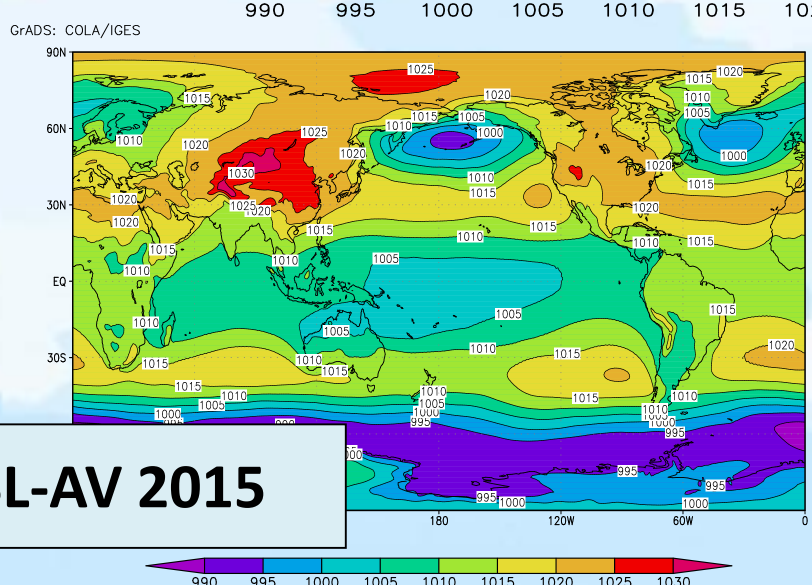
January zonal mean wind



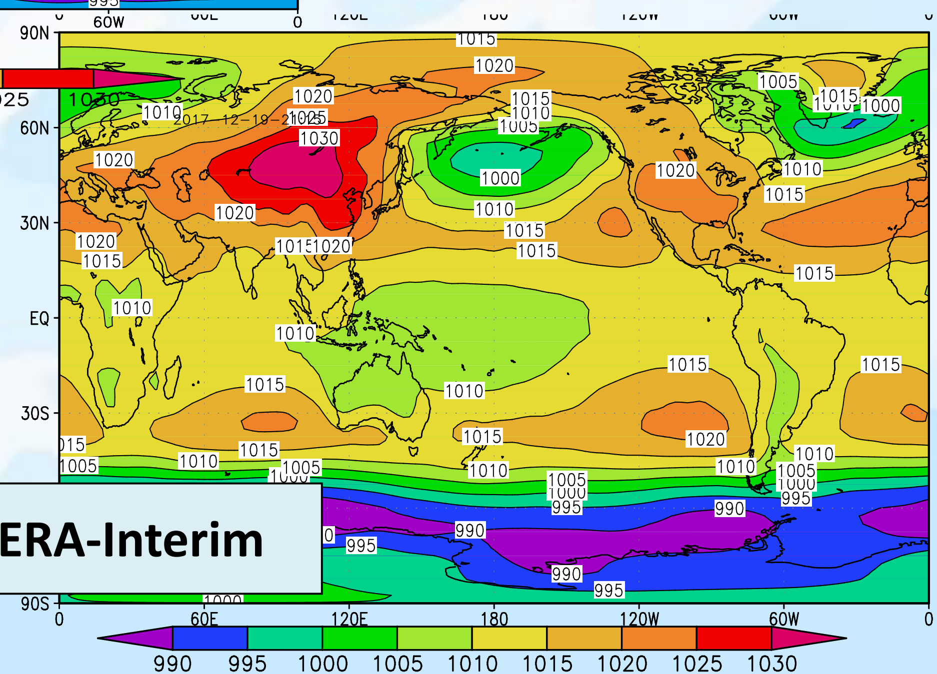
January Mean sea-level pressure 1979-1983



SL-AV 2018



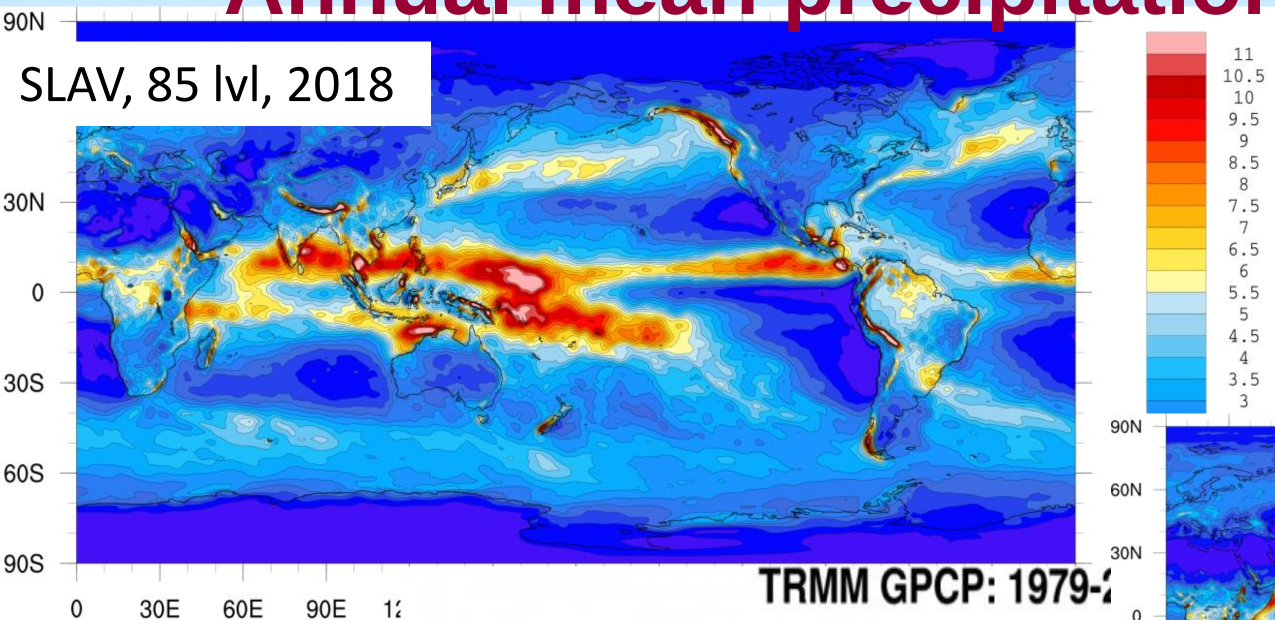
SL-AV 2015



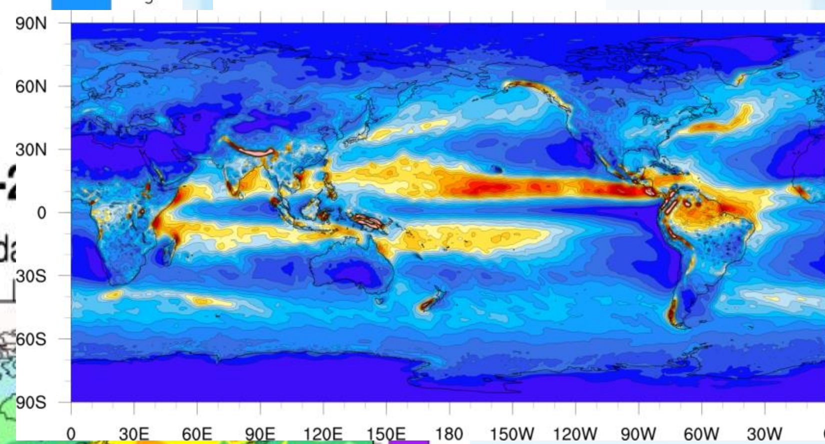
ERA-Interim

Annual mean precipitation (mm/day)

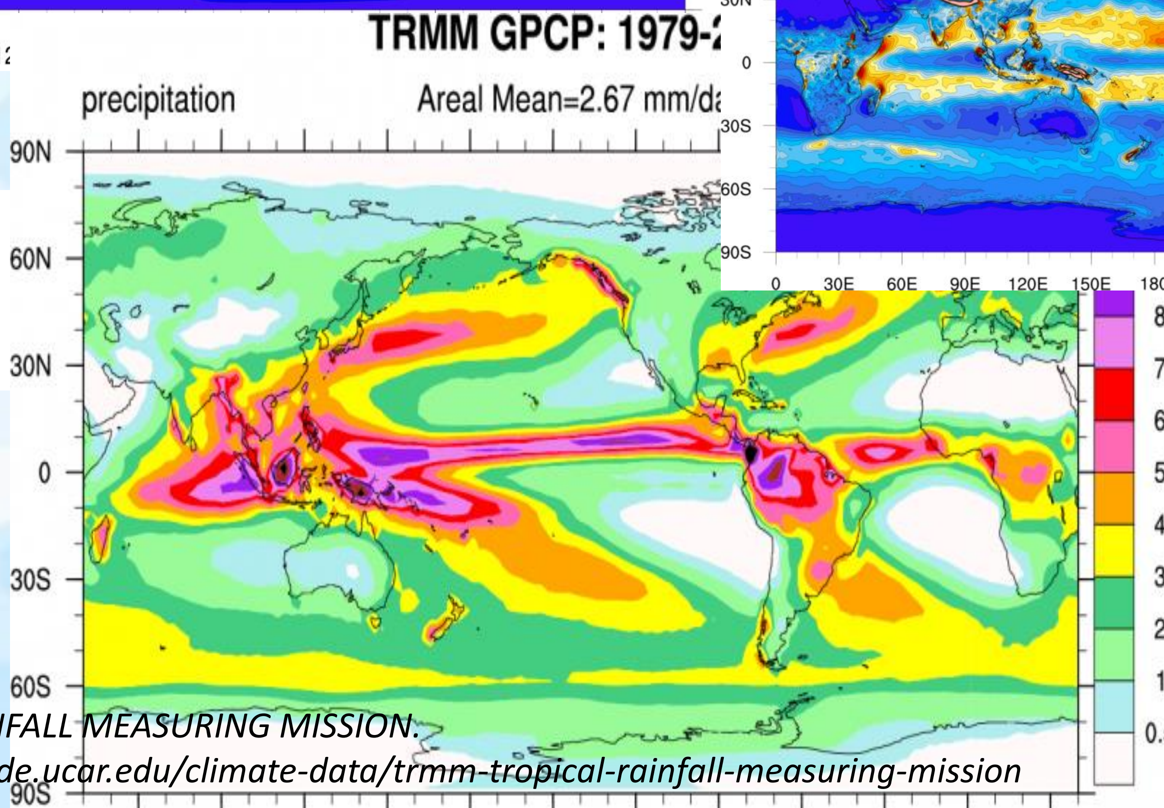
SLAV, 85 lvl, 2018



SLAV, 28 lvl, 2016

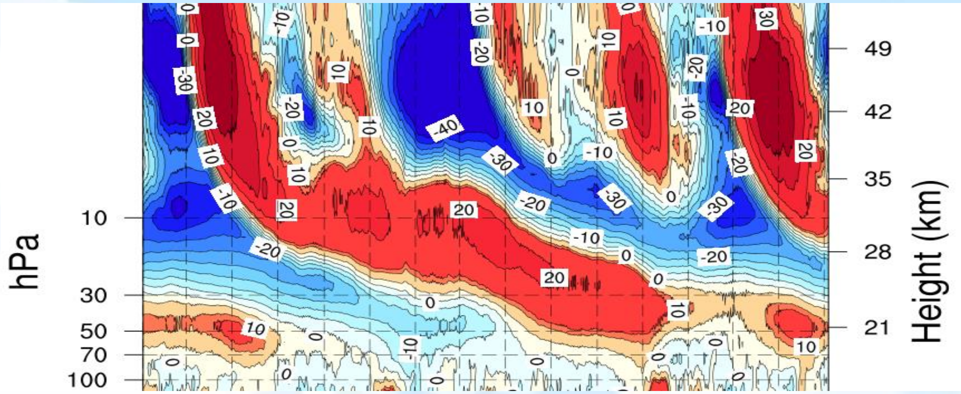


Obs GPCP
TRMM
(1979-2010)

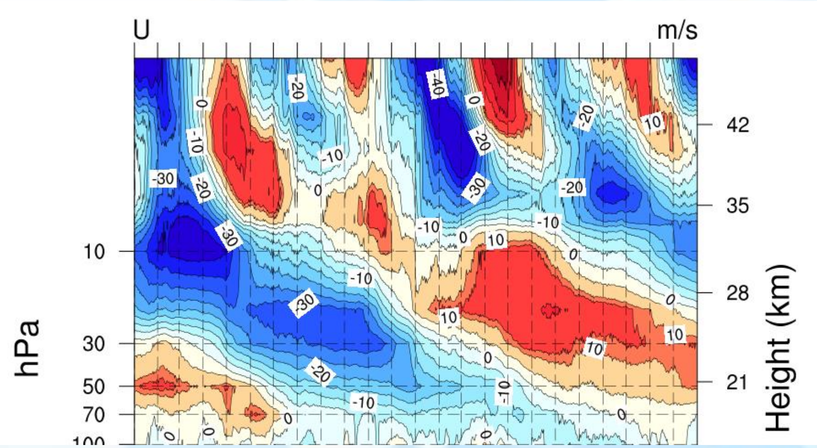


TRMM: TROPICAL RAINFALL MEASURING MISSION.
https://climatedataguide.ucar.edu/climate-data/trmm-tropical-rainfall-measuring-mission

Stratosphere: reproduction of quasi-biennial oscillation



SL-AV 2018



ERA-Interim

Coupled model components

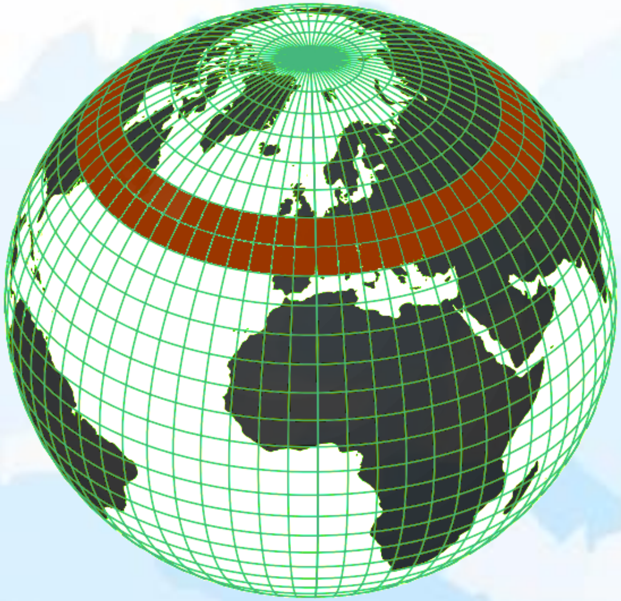
SLAV atmosphere model

0.9^ox0.72^o (400x250), **85** levels.

Δt = 1440 s.

Lat-Lon, 1D MPI decomposition.

* includes multilayer soil model.

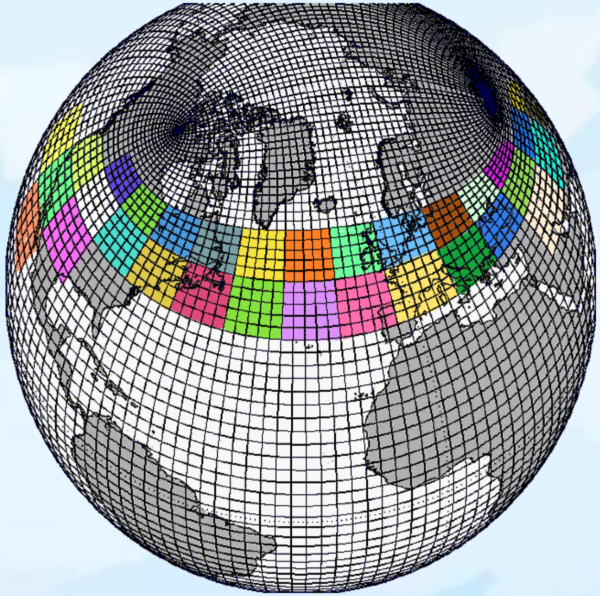


INMIO World ocean model

0.5^ox0.5^o (720x360), 49 levels.

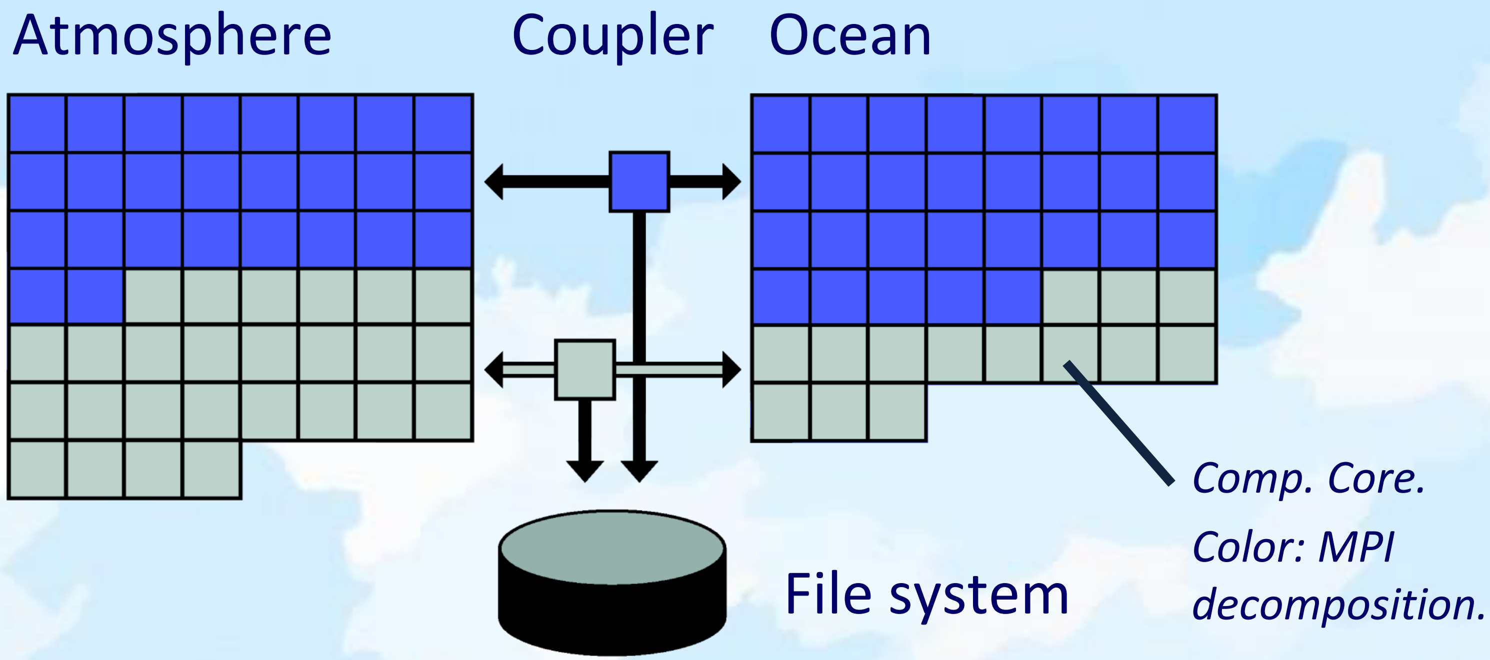
Δt = 600 s.

Tri-polar grid, 2D MPI decomposition.



Tolstykh et al, GMD, 2017;
Ibrayev et al, Izv AOP, 2012;
Fadeev et al, RJNAMM, 2016.

Coupled model structure



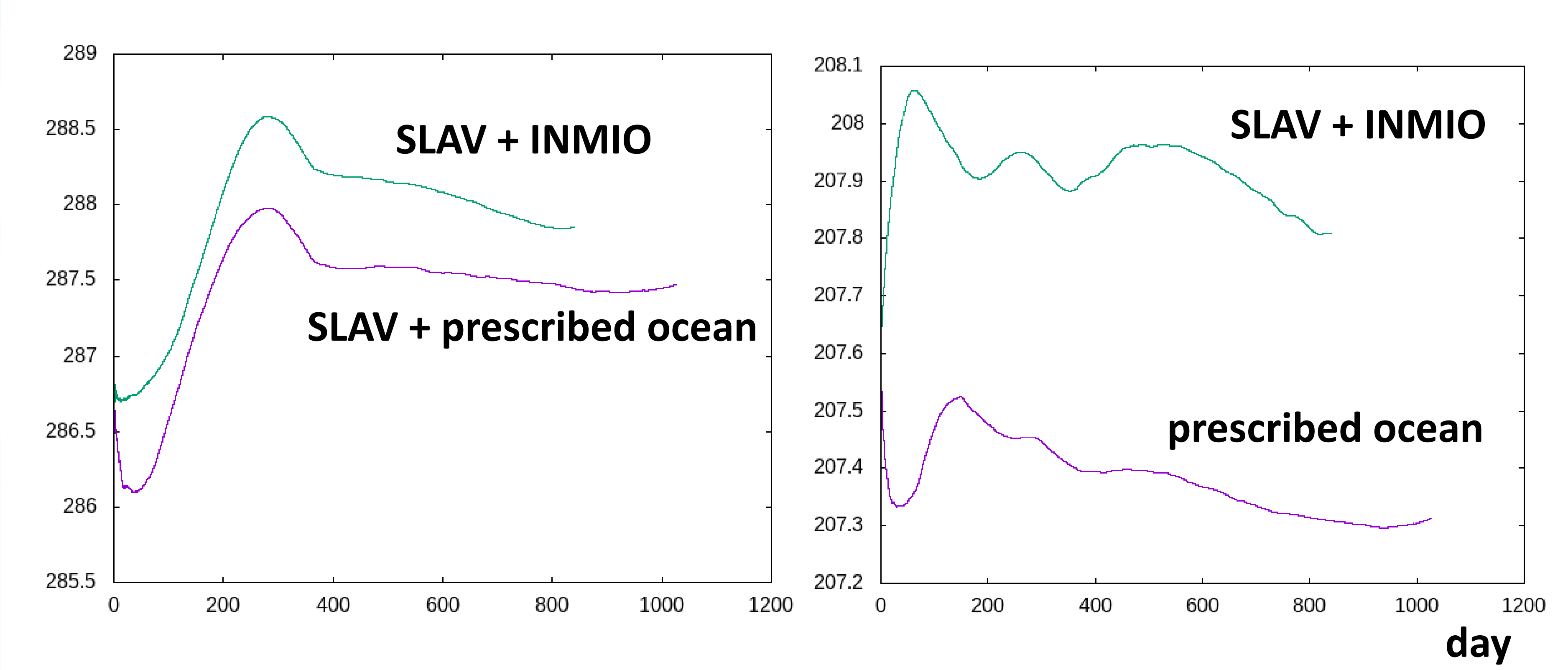
Coupler: synchronize the components, transfer (with interpolation) data between them, works with file system.

Data flow: 9 fields from atm to ocean every 2 hour,

3 fields from ocean to atm every 4 hour.

Efficiency: 2 years/day on 258 cores (ATM 125, OCN 132, CPL 1).

Global mean surface temperature (left), SST (right).

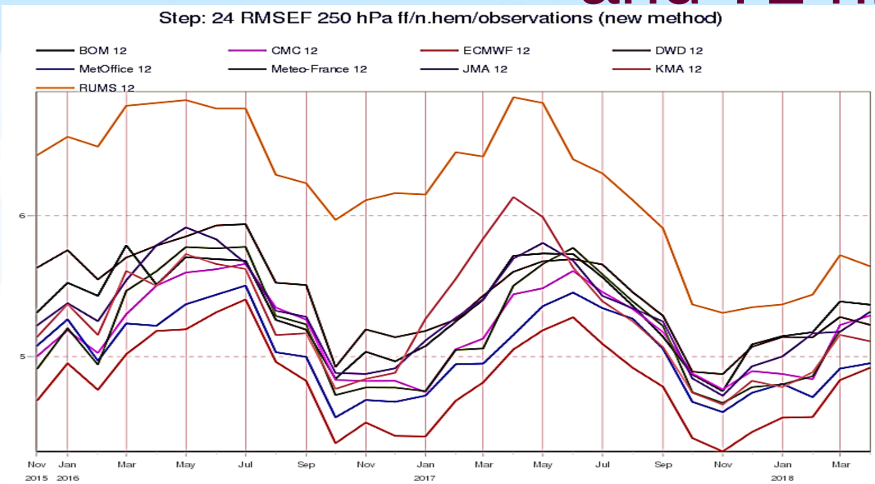


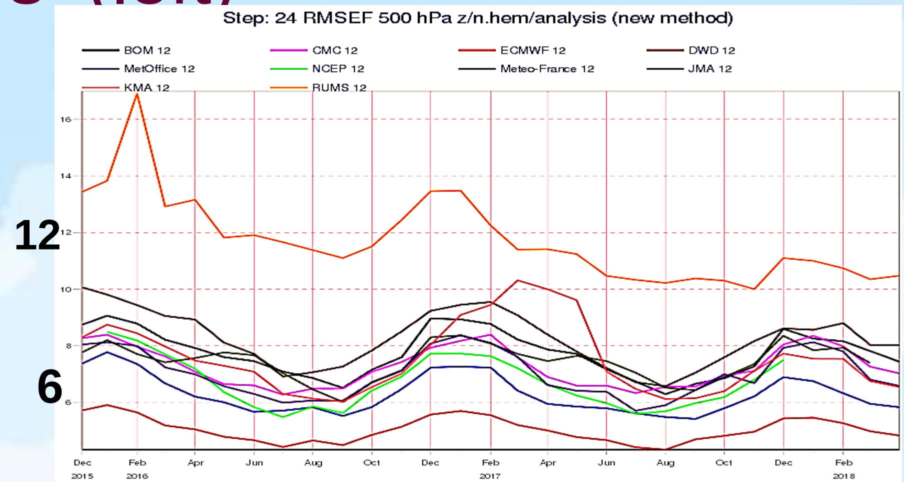
These improvements in model climate produced a reduction of operational medium range forecasts errors

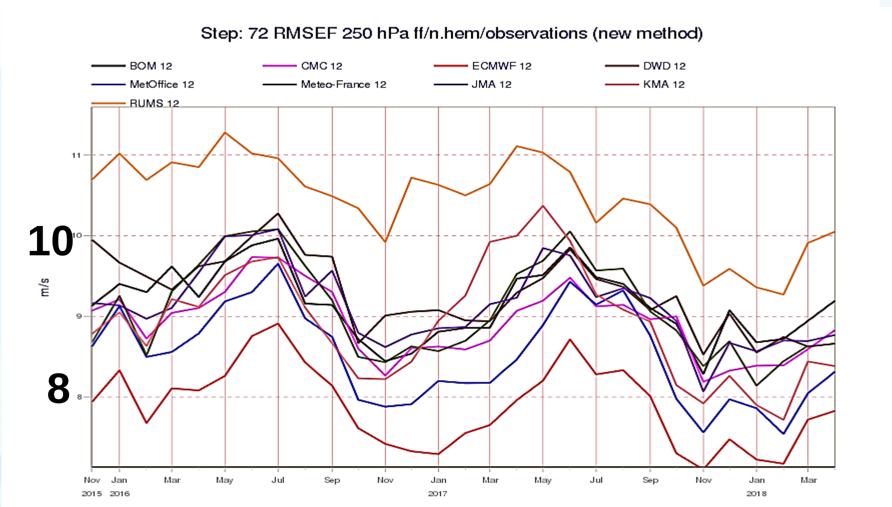
Operational version of the model: resolution in longitude 0,225°, in latitude from 0,16° in NH to 0,245° in SH, 51 vertical levels

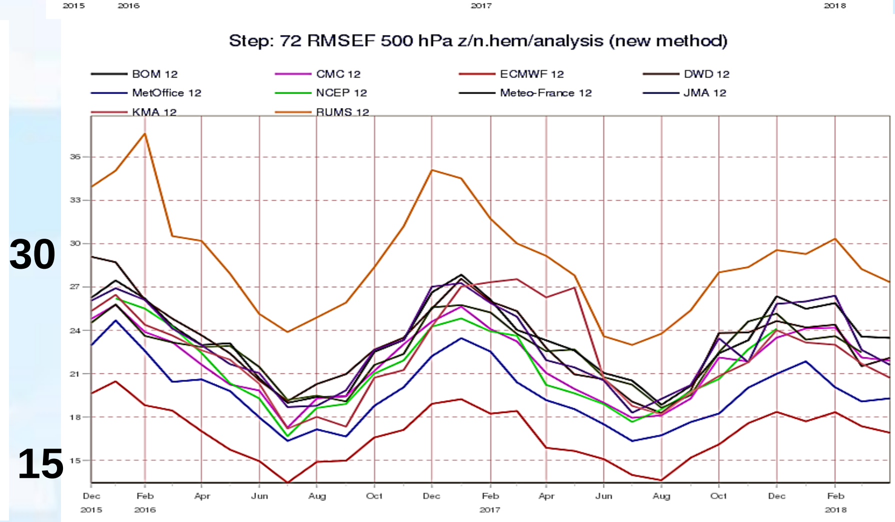
https://apps.ecmwf.int/wmolcdnv/

Reduction of SL-AV RMS forecast error (12.2015-04.2018). H500 at 24 and 72 hrs (right), W250 at 24 and 72 hrs (left)



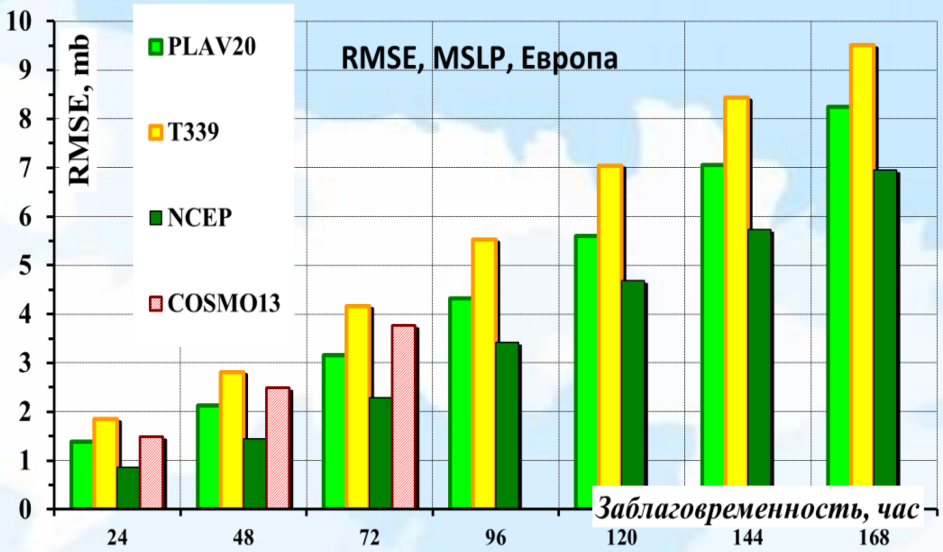


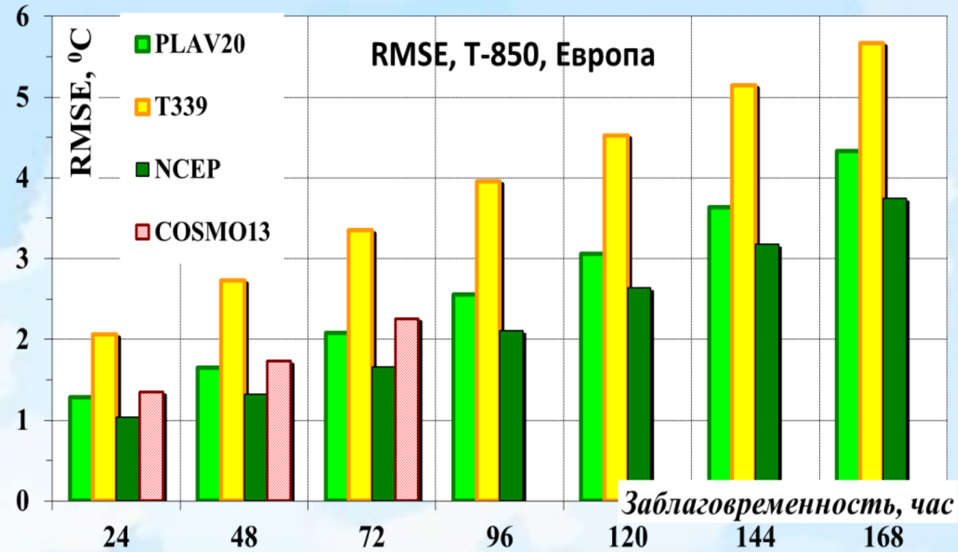


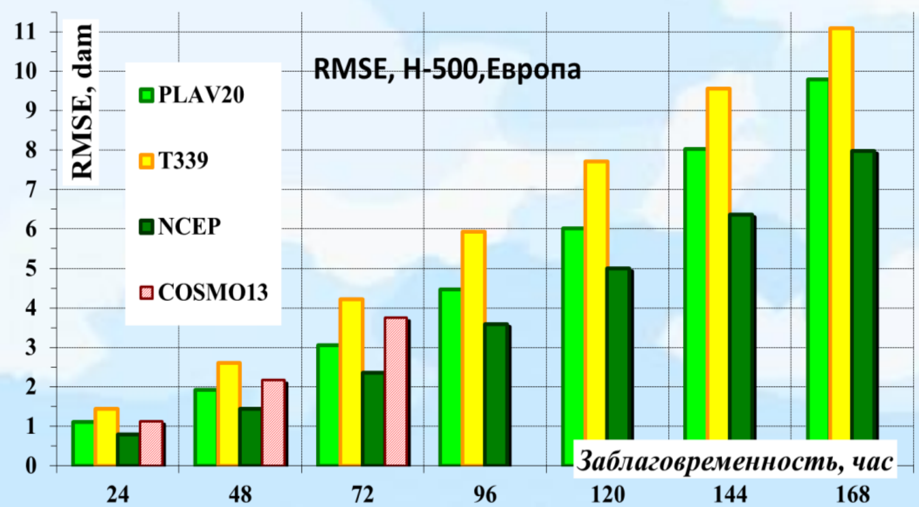


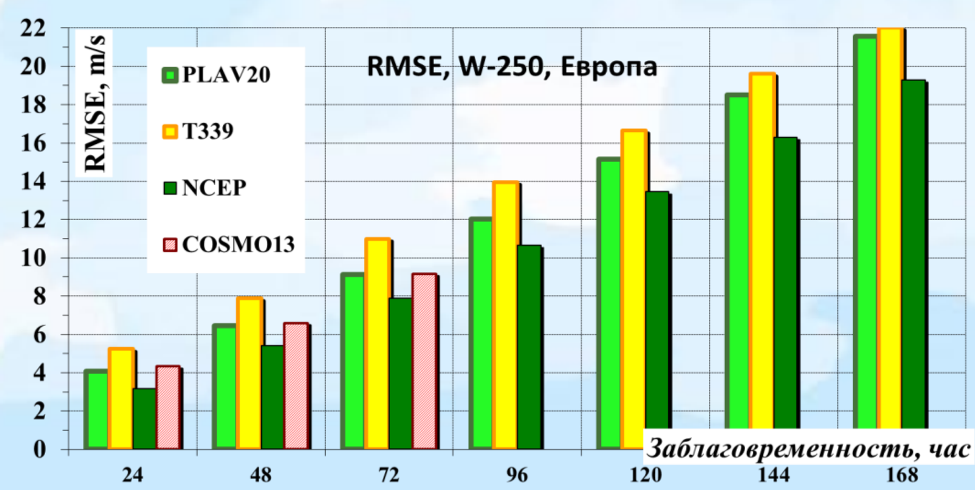
Reduction in H500 RMS eror: ~2,3 m (24hrs), 2,5m (72hrs), W250 RMS error: ~0,6 m/s (24hrs), 0.8 m/s (72 hrs). Discrepancy ~1.2 m/s in W250 72 hrs, ~4,5 m in в H500 72hrs

RMS errors of forecasts by different models over Europe averaged over 16.12.2017-07.05.2018
(computed in RHMC)

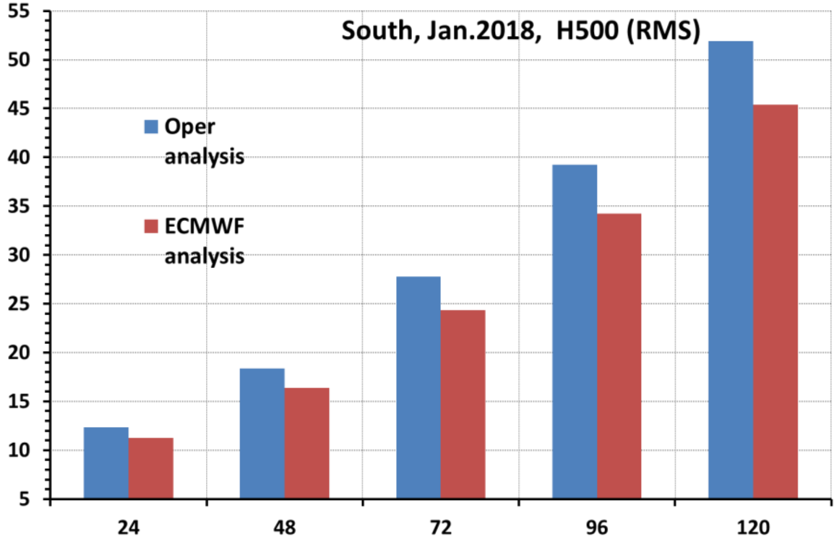


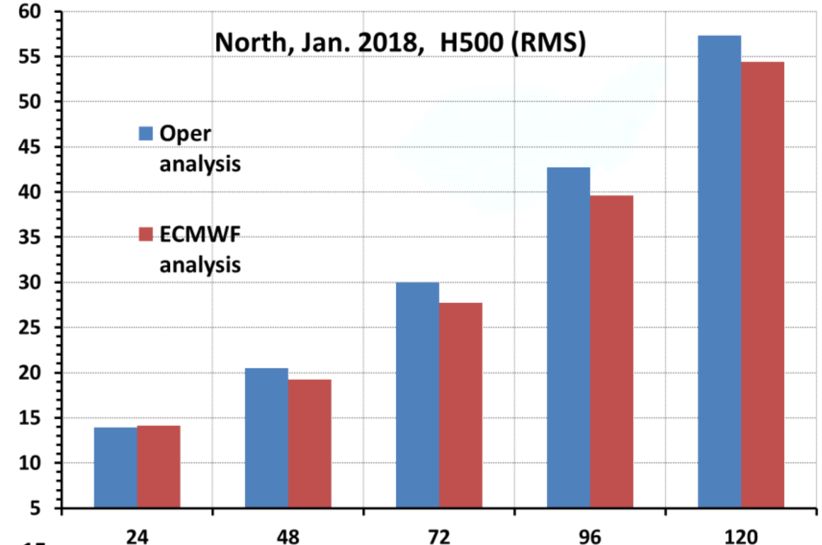


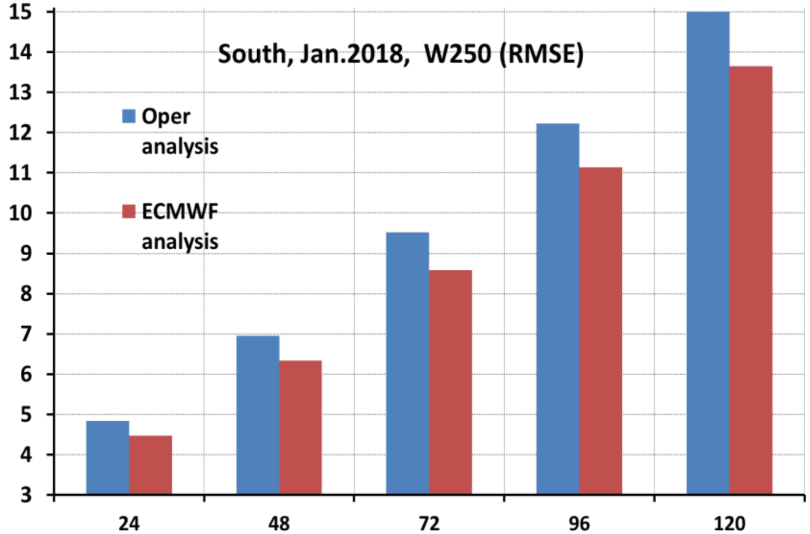


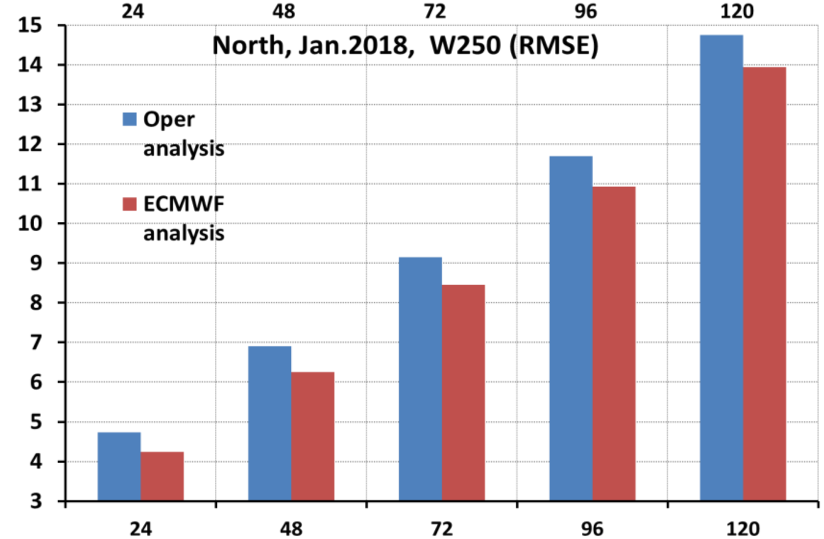


Improvements in RMS forecast error while using ECMWF initial data (Southern extratropics - left, Northern ones – right; top - H500 , bottom- W250)









Reduction in 72 hrs forecast error: geopotential – 2-4 m, wind ~ 0.8 m/s.

Conclusions

- New version of SL-AV model with 85 vertical levels reproduces main characteristics of modern climate, including stratosphere oscillations.

- Improvements in model climate helped to reduce medium-range forecasts errors.
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- Further modernization of SL-AV model is foreseen – Monte-Carlo independent column approach, deep convection parameterization with memory

Thank you for attention!

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