Sea ice in ocean reanalyses

Lessons and status from the ORA-IP and EU-COST EOS projects in the polar oceans

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Greg Smith[2], Jean-François Lemieux[2], Frédéric Dupont[2], Magdalena Balmaseda[3], Petteri Uotila[4], Hugues Goosse[5], Keith Haines[6], and many others

1- CNRM, Météo France/CNRS, France
2- ECCC, Canada
3- ECMWF, EU
4- FMI, Finland
5- UCL, Belgium
6- NCAS, UoR, UK

Outlines

- ORA-IP (CLIVAR GSOP / GODAE OceanView)
- Summary of ORA-IP ”Arctic sea ice paper” (Chevallier et al., 2016)
- PORA-IP (EU COST Action ”Evaluation of Ocean Syntheses”)
- Preliminary results on Antarctic sea ice
- …

Ocean ReAnalyses-Intercomparison Project

- CLIVAR GSOP and GODAE OceanView initiative, started 2011 (PI : Magdalena Balmaseda, ECMWF)
- 2 main objectives :
  - ✓ Estimating the noise from the ensemble spread
  - ✓ Gain insight into ocean variability by considering ensemble means

- Target variables, provided at the same format (netcdf, 1°x1°, monthly) :
  - Heat content (Mathew Palmer, MO)
  - Mixed layer depth (Takahiro Toyoda, MRI/JMA)
  - Salinity content (Li Shi, BOM)
  - **Sea ice concentration, thickness, velocity, snow (Matt Chevallier, MF ; Greg Smith, ECCC)**
  - Steric sea level (Andrea Storto, CMCC)
  - Heat fluxes (Maria Valdivieso, UoR)

- Data repository at University of Hamburg : ftp://ftp.icdc.zmaw.de/ora_ip/

- Project overview : Balmaseda et al. (2015), Journal of Operational Oceanography
- **Special issue of Climate Dynamics** (2016, all papers online)

ORA-IP : Arctic sea ice

In Climate Dynamics Special Issue …

Intercomparison of the Arctic sea ice cover in global ocean–sea ice reanalyses from the ORA-IP project

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✓ First-time ever systematic intercomparison of Arctic sea ice fields from global ORA…

✓ Benefits from past intercomparisons of **free regional/global models** :
- AOMIP/FAMOS (Johnson et al., 2007, 2011), CORE-II…

✓ Benefits from recent intercomparisons of **observational datasets** :
- Ivanova et al., 2014, 2015 (SIC);
- Zygmuntowska et al., 2014 (SIT);
- Sumata et al., 2014 (velocity)

ORA-IP : Arctic sea ice

Products	Centre	Horiz Res.	Sea ice model	Atm forcing	Sea ice DA scheme	Sea ice data
C-GLORS	CMCC	0.5°	LIM2	ERA-I	**Linear nudging**	NSIDC
ECCO-v4	MIT	0.5°	MITgcm	ERA-I	**Adjoint**	NSIDC
ECDA	GFDL	1°	SIS	NCEP CPL	None	-
GloSea5	UKMO	0.25°	CICE	ERA-I	**3DVAR**	OSI-SAF
MERRA	GMAO	0.5°	CICE	MERRA CPL	**EnOI**	NSIDC
GLORYS2V1	Mercator	0.25°	LIM2	ERA-I	None	-
GLORSY2V3	Mercator	0.25°	LIM2	ERA-I	**SEEK**	CERSAT
MOVE-CORE	MRI	0.5°	~CICE	CORE (NCEP)	None	-
MOVE-G2	MRI	0.5°	~CICE	JRA-55	None	-
ORAP5	ECMWF	0.25°	LIM2	ERA-I	**3DVAR**	OSTIA
UR025.4	NCAS	0.25°	LIM2	ERA-I	**OI**	OSISAF
CNRM	CNRM	1°	GELATO	ERA-I	None	-
ERAL	*ECMWF*	*1°*	*LIM2*	*ERA-I*	***Linear nudging***	*OIv2*
ERAN	*ECMWF*	*1°*	*LIM2*	*ERA-I*	***Non-lin. nudg.***	*OIv2*

- ✓ERA-Interim
- ✓LIM2 vs CICE or ITD
- ✓2 coupled RA
- ✓**9/14 with sea ice DA**
- ✓**All other 5 : SST restoring/ocean DA**
- ✓*Research mode*
- ✓Common period: **1993-2007**

Table 1 System configuration and selected parameters

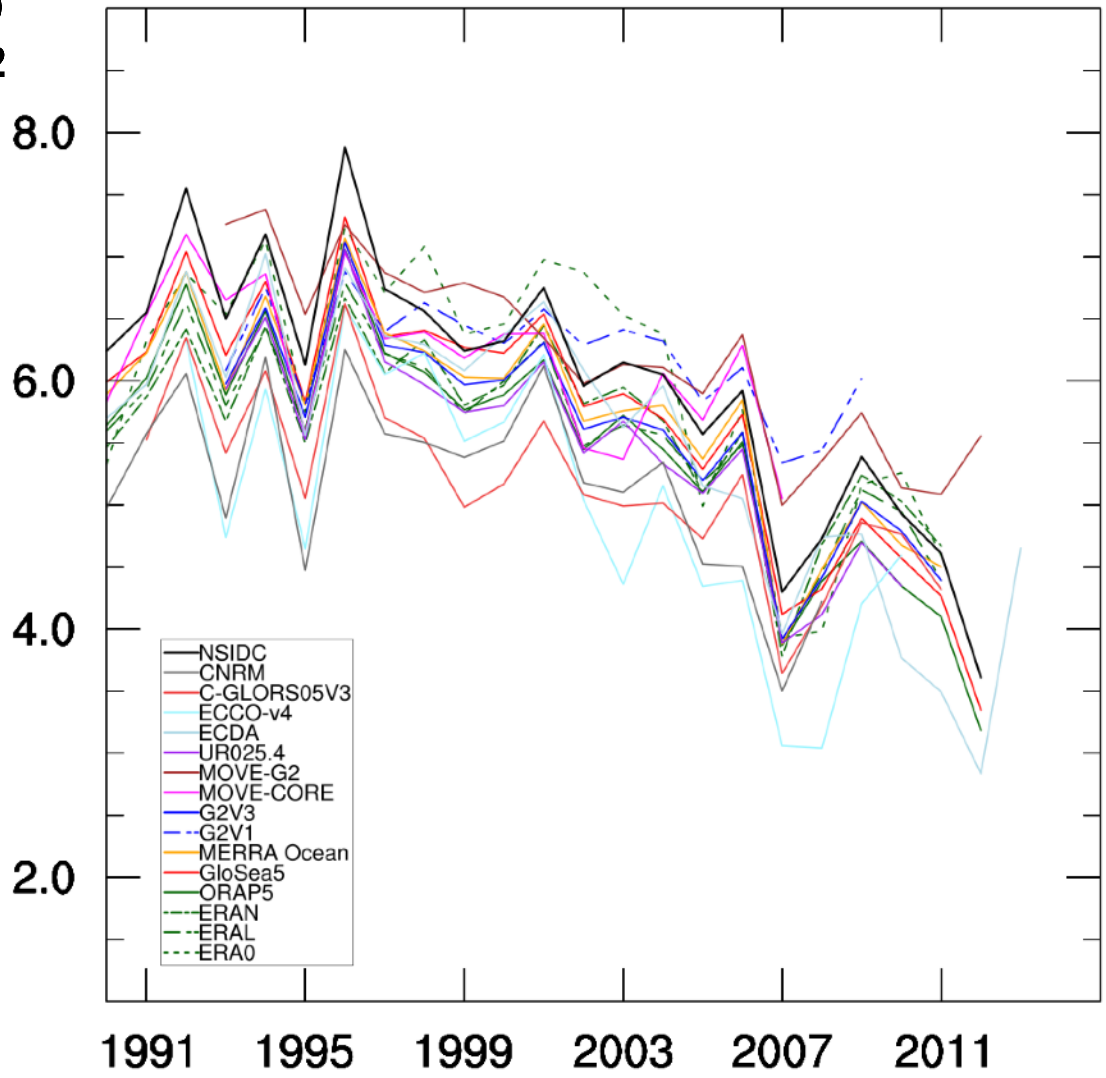
Name	C-GLORS05	CNRM	ECCO-v4	ECDA	GloSea5	G2V3	MERRA Ocean	MOVE-CORE	MOVE-G2	ORAP5	UR025.4	G2V1	ERAL	ERAN
Institution	CMCC	CNRM-GAME	JPL/NASA, MIT, AER	GFDL/NOAA	UK Met Office	Mercator Océan	GSFC/NASA/GMAO	MRI/JMA	MRI/JMA	ECMWF	University of Reading	Mercator Océan	ECMWF	ECMWF
Nominal horizontal resolution	0.5°	1°	0.4°–1.0°	1°	0.25°	0.25°	0.5°	0.5° × 1°	0.3–0.5° × 1°	0.25°	0.25°	0.25°	1°	1°
Ocean–sea ice model	NEMO3.2-LIM2	NEMO3.2-GELATO5	MITgcm	GFDL-MOM4.4.1-SIS	NEMO3.2-CICE4.0	NEMO3.1-LIM2 (EVP)	MOM4.1-CICE4.0	MRI.COM3-Mellor & Kanta + CICE4.0	MRI.COM3-Mellor & Kanta + CICE4.0	NEMO3.4-LIM2	NEMO3.2-LIM2	NEMO3.1-LIM2 (EVP)	NEMO3.2-LIM2	NEMO3.2-LIM2
Time period	1979–2011	1990–2010	1992–2010	1961–2014	1993–2012	1993–2011	1979-present	1948–2007	1993–2012	1979–2012	1989–2010	1993–2009	1990–2011	1990–2011
Source of atmospheric forcing data	ERA-Interim	ERA-Interim	ERA-Interim	Coupled run constrained to NCEP/NCAR-NCEP/DOE	ERA-Interim	ERA-Interim	Coupled run constrained to MERRA	CORE	JRA55	ERA-Interim	ERA-Interim	ERA-Interim	ERA-Interim	ERA-Interim
Vertical discretization	2 ice + 1 snow	9 ice + 1 snow	1 ice + 1 snow	2 ice + 1 snow	1 ice + 1 snow	2 ice + 1 snow	4 ice + 1 snow	1 ice + 1 snow	1 ice + 1 snow	2 ice + 1 snow	2 ice + 1 snow	2 ice + 1 snow	2 ice + 1 snow	2 ice + 1 snow
Thickness categories	1	8	1	5	5	1	5	5	5	1	1	1	1	1
Dynamics	EVP	EVP	VP	EVP	EVP	EVP	EVP	EVP	EVP	VP	VP	EVP	VP	VP
P* (N/m)/ Cf (–)	P* = 2.0×10^4	P* = 2.75×10^4	P* = 2.754×10^4	P* = 2.5×10^4	Cf = 17	P* = 2×10^4	P* = 2.75×10^4	P* = 2.75×10^4	P* = 2.75×10^4	P* = 1.50×10^4	P* = 1×10^4	P* = 2×10^4	P* = 1.5×10^4	P* = 1.5×10^4
Drag air–ice (10-3)	1.63	1.63	2.00	1.21	1.63	1.50	1.63	3.00	1.00	1.63	1.63	1.50	1.63	1.63
Drag ocean–ice (10-3)	10.00	5.00	1.00	3.24	5.36	10.00	5.36	5.50	5.50	10.00	5.00	10.00	5.00	5.00
DA sea ice system	Linear nudging	None (SST)	Adjoint	None (SST)	3DVAR	2D local analysis SEEK filter	EnOI	None (SST)	None (SST)	3DVAR-FGAT	OI	None (SST)	Linear nudging	Flow-dependent nudging
DA sea ice data	NSIDC	–	NSIDC	–	OSI-SAF	CERSAT	NSIDC	–	–	OSTIA	OSI-SAF	–	NCEP-OIv2	NCEP-Oiv2
Analysis window	7 days	10 days	20 years	1 day	1 day	7 days	5 days	1 month	1/3 month	5 days	5 days	7 days	1 day	1 day

P* and Cf are parameters for the ice strength formulations following respectively Hibler (1979) and Rothrock (1975)

DA data assimilation, *VP* viscous-plastic, *EVP* elastic–viscous–plastic, *SST* sea surface temperature

Sea ice concentration/areas/extent

Sea ice extent (Mkm²)
September 1990-2012

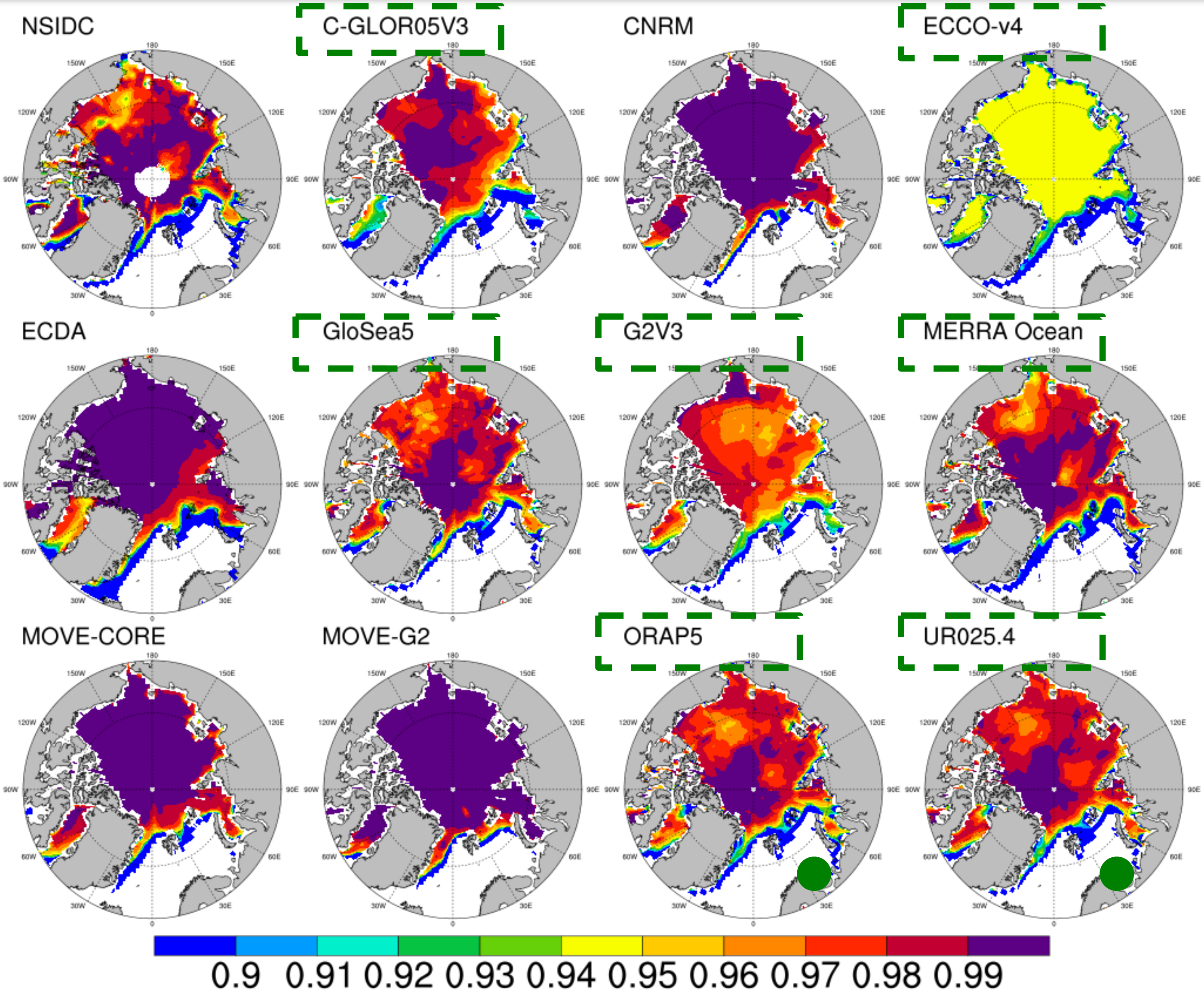


Chevallier et al., 2016, CLIMDYN

Sea ice concentration/areas/extent

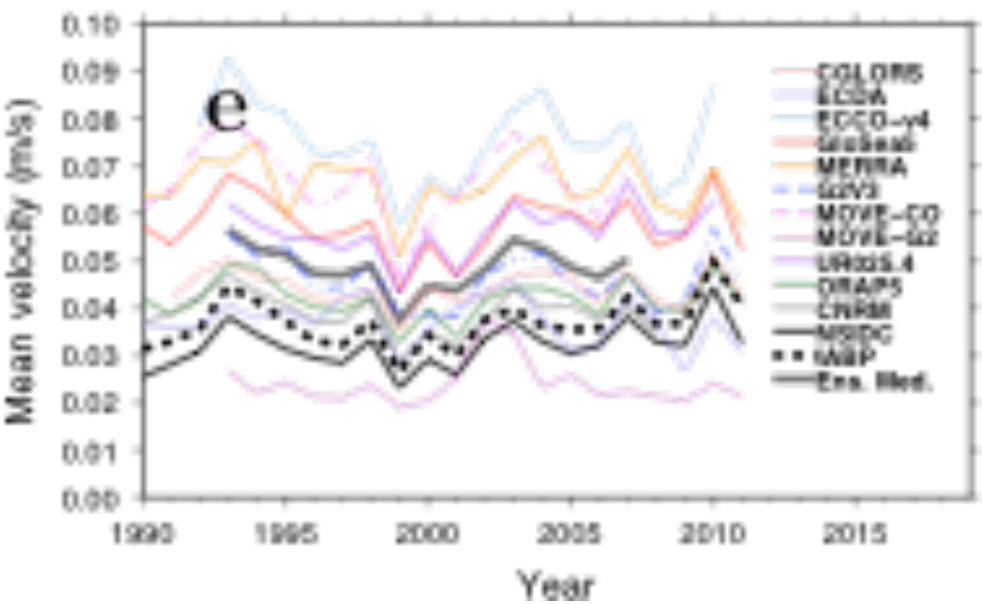
Sea ice concentration
March 2007
SIC > 90%

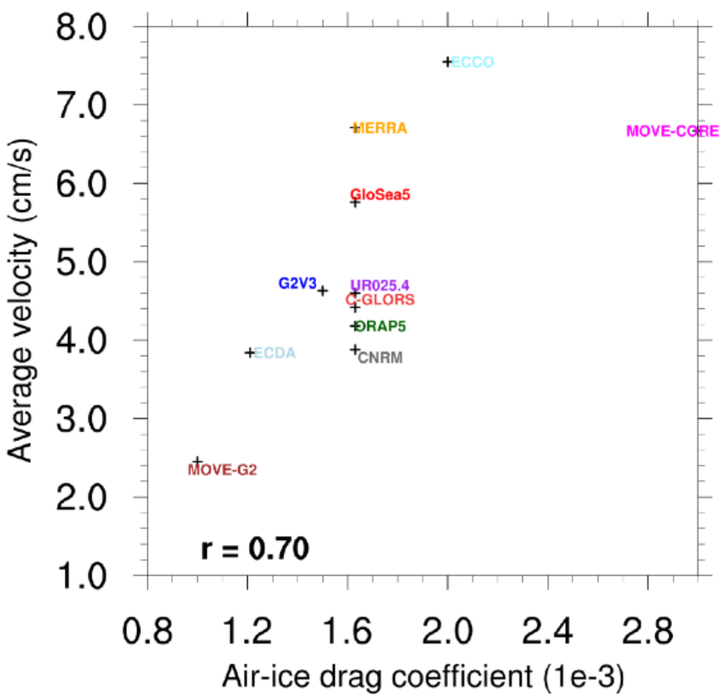
SIC DA



Sea ice velocity

Arctic mean sea ice velocity: Annual mean



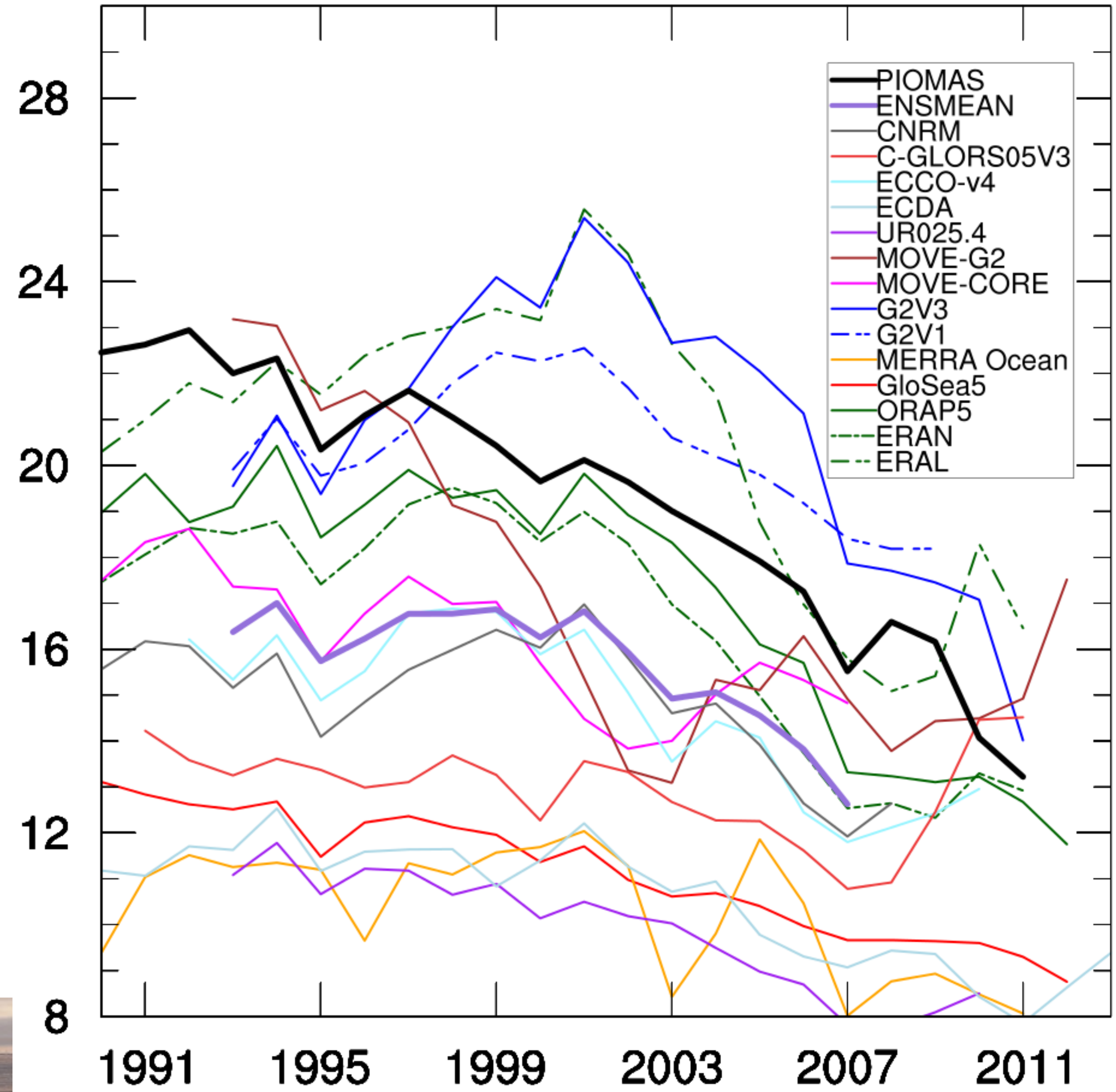


- Realistic year-to-year variability (response to the forcing)
- The ensemble overestimates sea ice velocity
- Velocity biases can be related to model (tuning) parameters

Chevallier et al., 2016, CLIMDYN

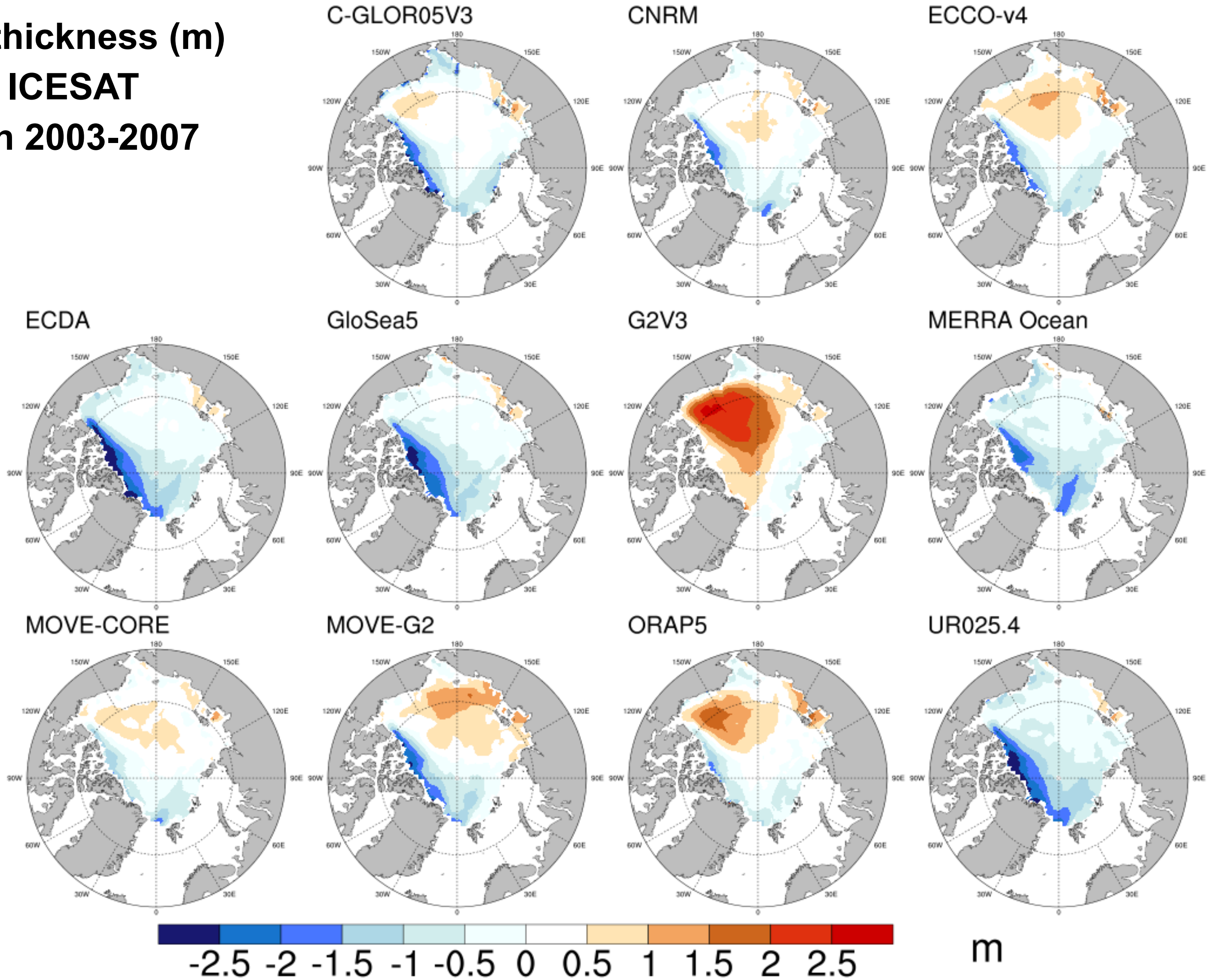
Sea ice thickness/volume

Annually-averaged Arctic sea ice volume (10^3 km^3)



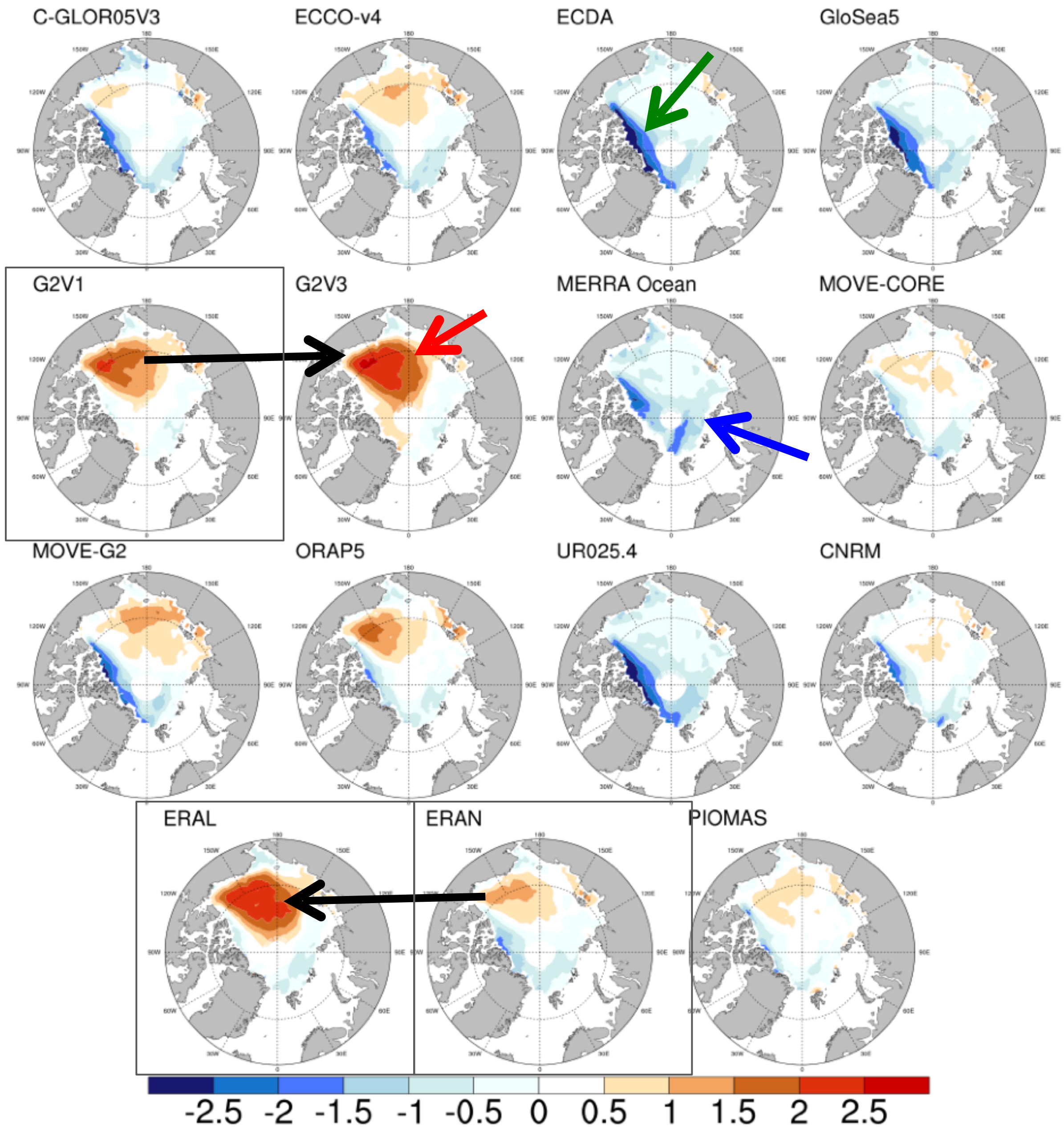
Sea ice thickness/volume

Mean sea ice thickness (m)
Difference wrt ICESAT
Average March 2003-2007



Chevallier et al., 2016, CLIMDYN

Sea ice thickness/volume



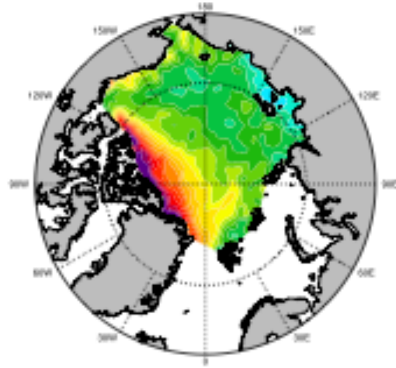
Mean sea ice thickness (m)
Difference wrt ICESAT
Average March 2003-2007

✓Too thin ice north of Canada
✓Too thick ice in the Beaufort sea
✓Too thin ice in Atlantic sector

'Thick Spot' in Beaufort sea :

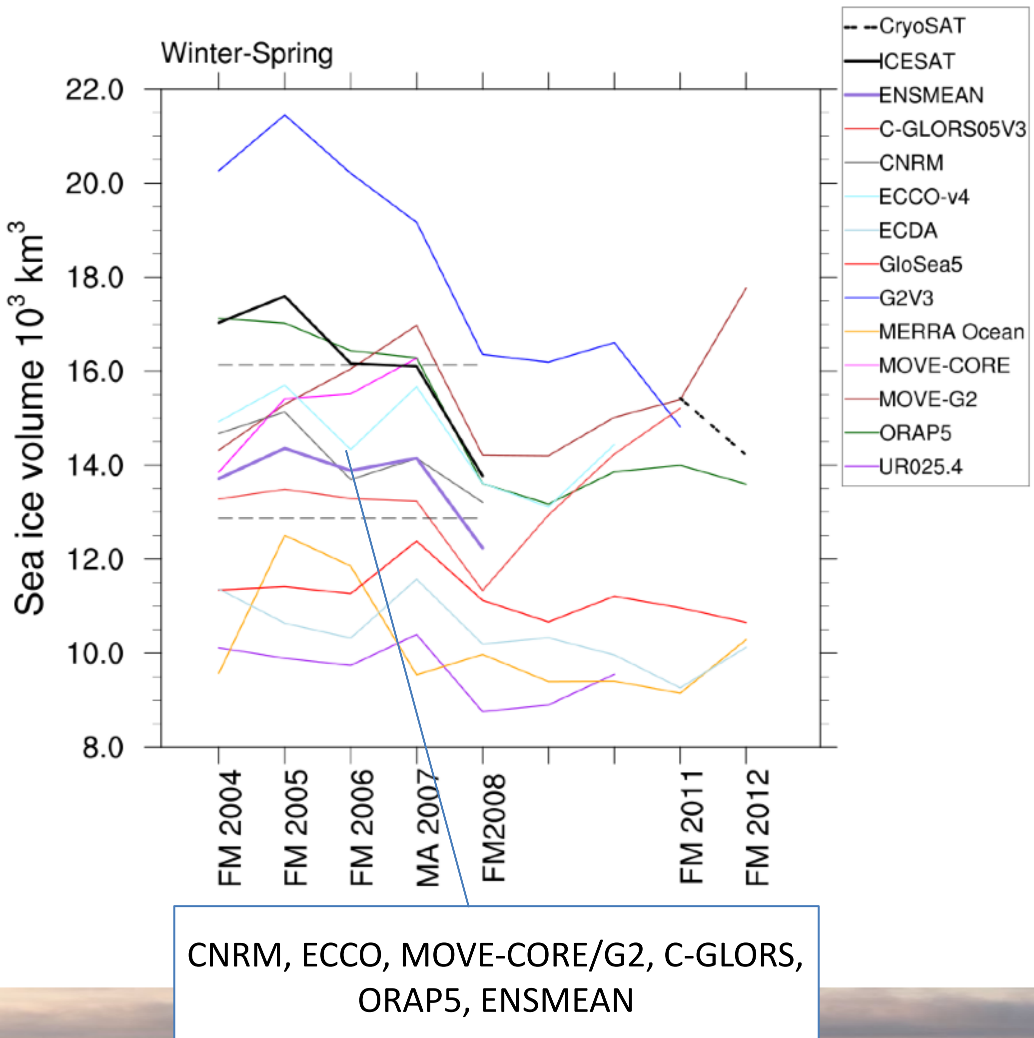
G2V1 → G2V3: no-DA vs DA
ERAN → ERAL: DA techniques?

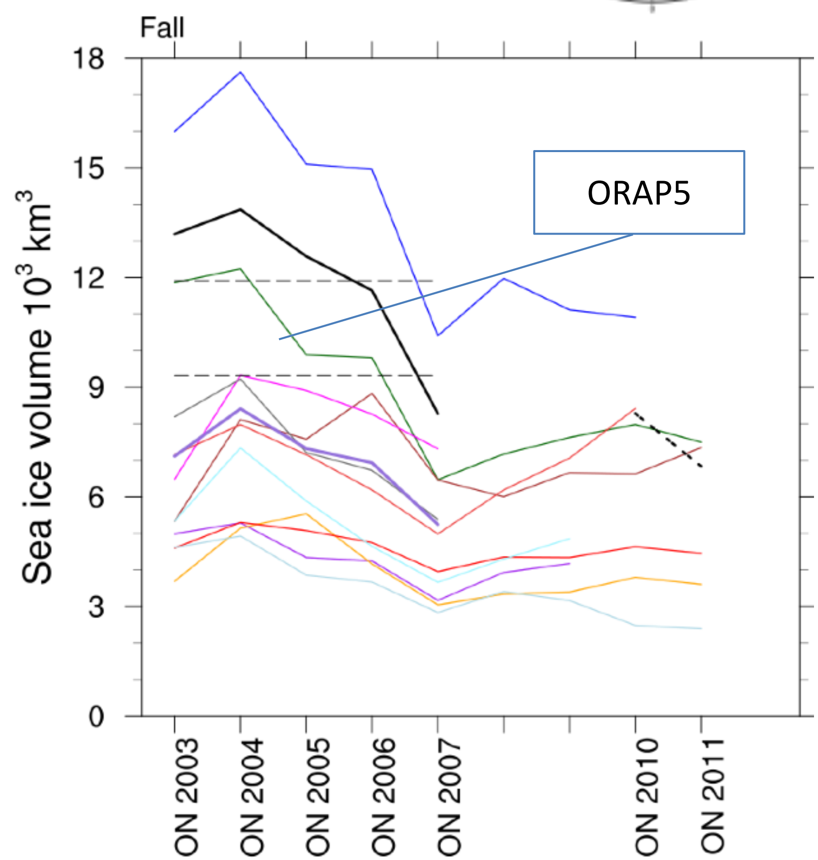
Sea ice thickness/volume



Arctic sea ice volume (over the ICESat domain)

Comparison with ICESat-JPL and Zygmuntowska et al's uncertainty estimate





Polar ORA-IP (PORA-IP)

- Led by Petteri Uotila (FMI, Finland); part of the EU COST ES-1402 “Evaluation of Ocean Syntheses“ (2014-2018)

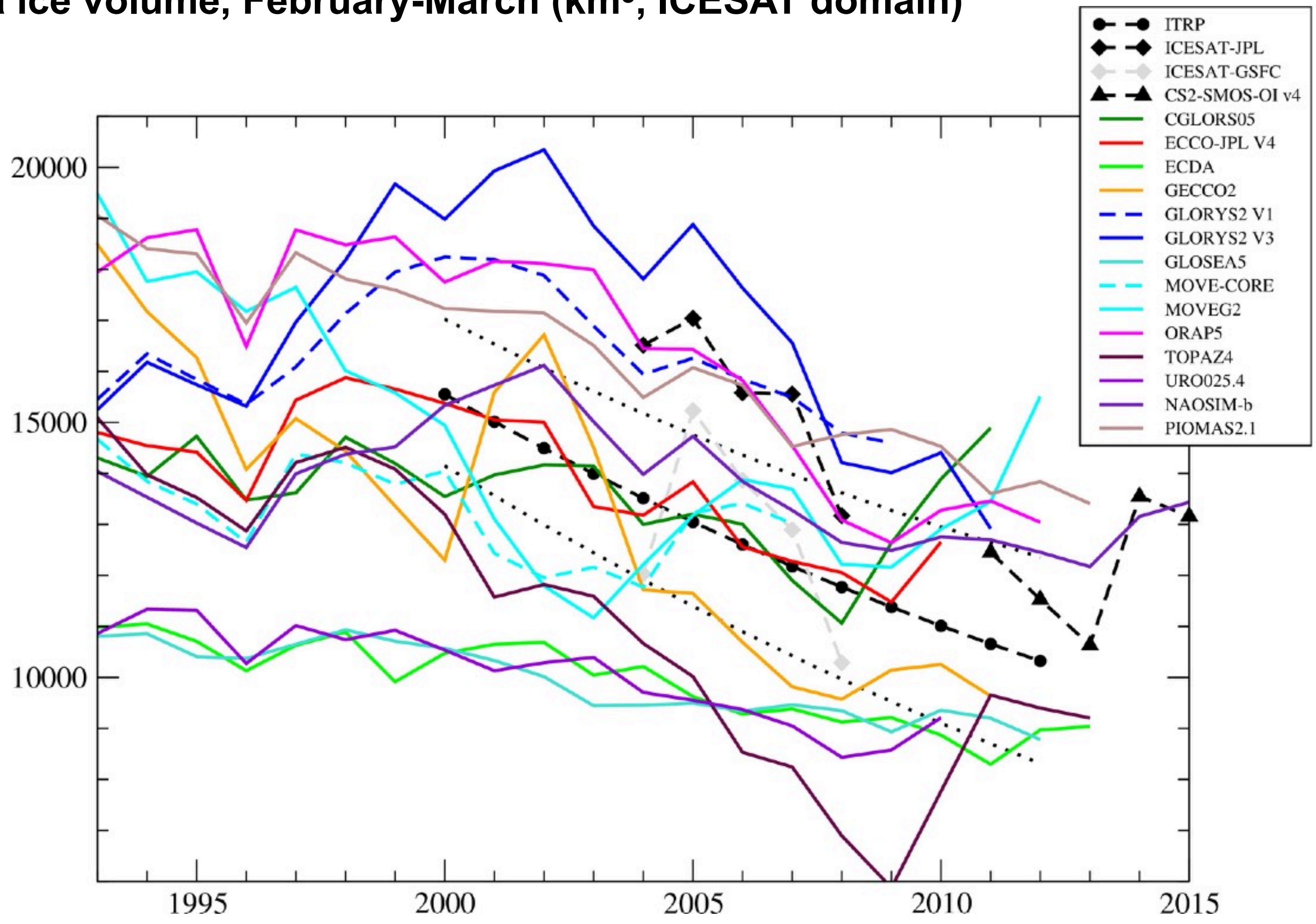
- Participants : AWI, BSC, CMCC, ECMWF, FMI, Mercator Océan, MF, MO, NERSC, UoR, UCL.

- Intensive verification process of ORA products in the Arctic Ocean **and** Southern Ocean :
  - ✓ Hydrography (FMI)
  - ✓ Heat and salinity content (UoR)
  - ✓ Freshwater content (CMCC)
  - ✓ Ocean transports and currents (Mercator Océan, BSC)
  - ✓ Mixed layer depth (UCL)
  - ✓ Sea ice concentration and thickness (AWI, MF, UCL)

- Use of updated versions of global ORA :
  - ✓ GLORYS2v4, ORAS5…
- Inclusion of regional ORA :
  - ✓ PIOMAS, TOPAZ4, NAOSIM
- Use of new observational datasets :
  - ✓ Arctic sea ice thickness ITRP (UoW), hydrography climatology by H. Sumata (AWI)…

Polar ORA-IP (PORA-IP)

Arctic sea ice volume, February-March (km^3, ICESAT domain)

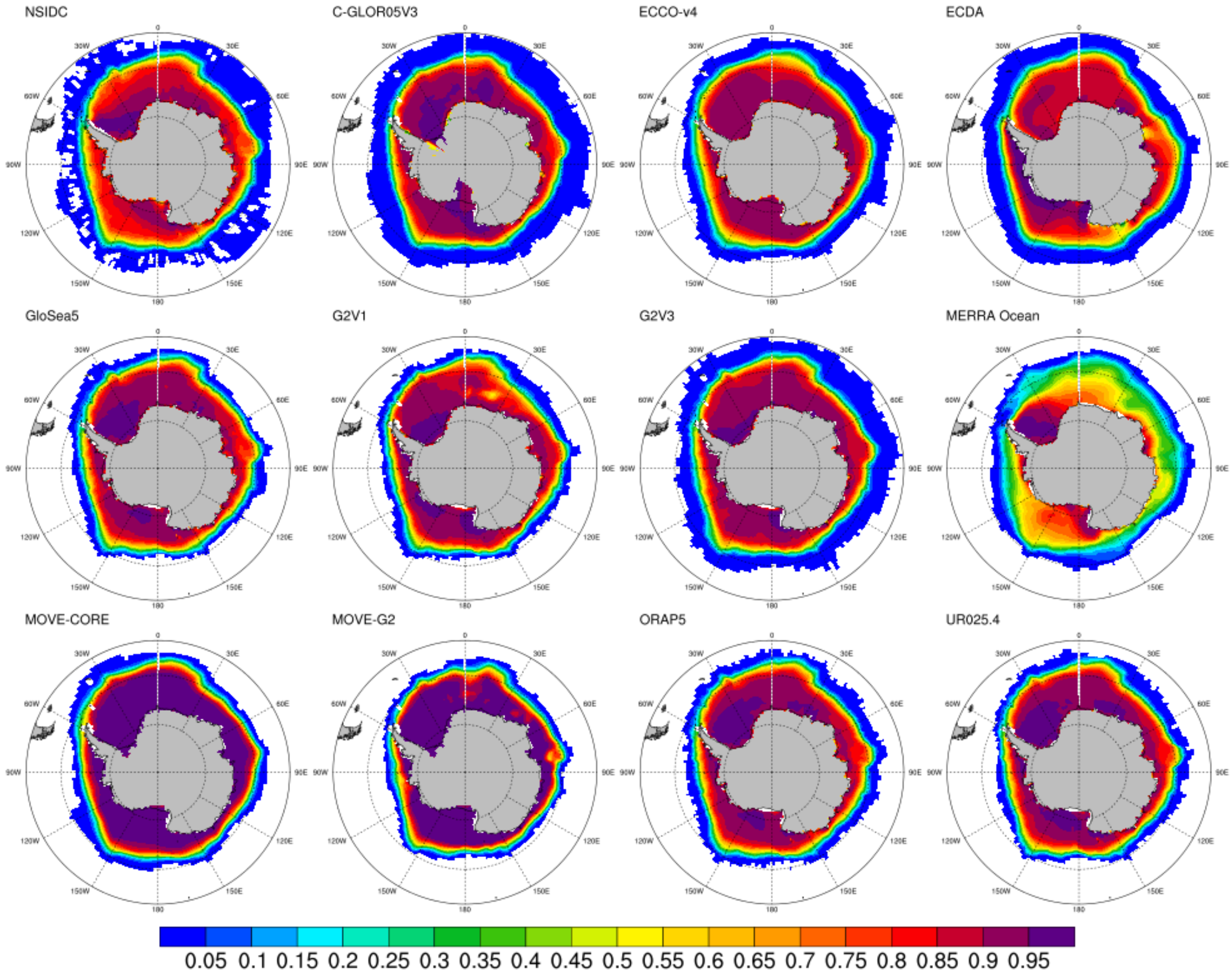


Courtesy Frank Kauker (AWI)

ITRP : Lindsay and Schweiger, TC, 2015

Polar ORA-IP (PORA-IP)

Antarctic sea ice concentration, average September 1993-2007



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A few thoughts

- **A comprehensive database has been set up (common grid, various properties)**

- **PORA-IP : 2 papers in preparation.**

- Potential for new studies :
  - Coupled diagnostics (ocean ⍰ sea ice)
  - Use of ORA product to force AGCMs (AMIP mode) → impact on surface fluxes
  - **Statistical predictability studies (collab. SIPN?)**
  - Explore the value of coupled reanalyses…

- This kind of analyses is challenging :
  - Not a coordinated framework (different forcings, forced vs coupled models)
  - Still some information lacking (spinup/initial states…)
  - Sometimes hard to know what is actually assimilated in the polar oceans
  - **Systematic comparison with free runs (non-assimilating) : often done by producers**
  - **Use of “light models“ to carry out sensitivity studies…**

- Near-real-time database for YOPP?

ftp://ftp.icdc.zmaw.de/ora_ip/

Thank you for your attention

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YOPP YEAR OF POLAR PREDICTION

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Ocean ReAnalyses-Intercomparison Project

Table 2. List of Ocean Reanalysis products entering the inter-comparison.

Product	Forcing	Configuration	Data Assim. Method
ARMOR3D[a,b] CLS	N/A	1/3° Obs-Only (T/S/SSH/U/V)	*OI (SLA/MDT/T/S/SST)*
CFSR[c,d] NOAA NCEP	Coupled DA	1/2° MOM4 coupled	*3DVAR (T/SST/SIC)*
C-GLORS05V3[e] CMCC	ERAi corr+Bulk	1/2° NEMO3.2	*3DVAR (SLA/T/S/SST/SIC)*
ECCO-NRT[f] JPL/NASA	NCEP-R1 +CORE Bulk	1° MITgcm	*KF-FS (SLA/T)*
ECCO-v4[g,h] MIT/AER/JPL	ERAi+CORE Bulk	1° MITgcm	*4DVAR (SLA/SSH/T/S/SST)*
EN3 v2a[i] Hadley Center	N/A	1° Obs-Only (T/S)	*OI (T/S)*
GECCO2[j] U. of Hamburg	NCEP-R1+Bulk	1°×1/3° MITgcm	*4DVAR (SLA/T/S/MDT/SST)*
ECDA[k,l] GFDL/NOAA	Coupled DA	1/3° MOM4 coupled	*EnKF (T/S/SST)*
GloSea5[m,n] UK MetOffice	ERAi+CORE Bulk	1/4° NEMO3.2	*3DVAR (SLA/T/S/SST/SIC)*
MERRA Ocean GSFC/NASA/GMAO	Merra +Bulk	1/2° MOM4	*EnOI (SLA/T/S/SST/SIC)*
GODAS[o] NOAA NCEP	NCEP-R2 Flux.	1°×1/3° MOM3	*3DVAR (SST/T)*
GLORYS2V1(G2V1) Mercator Océan	ERAi corr+CORE Bulk	1/4° NEMO3.1	*KF+3DVAR (SLA/T/S/SST/SIC)*
GLORYS2V3(G2V3) Mercator Océan	ERAi corr+CORE Bulk	1/4° NEMO3.1	*KF+3DVAR (SLA/T/S/SST/SIC)*
K7-ODA(ESTOC)[p] JAMSTEC/RCGC	NCEP-R1 corr. Flux	1° MOM3	*4DVAR (SLA/T/S/SST)*
K7-CDA[q] JAMSTEC/CEIST	Coupled DA	1° MOM3 coupled	*4DVAR (SLA/SST)*
LEGOS[r] LEGOS	N/A	1/4° Obs-Only (SL)	*OI+EOF (SLA/SSH)*
NODC[s] **NODC/NOAA**	N/A	1° Obs-only (T/S)	*OI (T/S)*
PEODAS[t] CAWCR(BoM)	ERA40 to 2002; NCEP-R2 thereafter.	Flux 1°×2° MOM2	*EnKF (T/S/SST)*
ORAS4[u,v] ECMWF	ERA40 to 1988; ERAi thereafter. Flux.	1° NEMO3	*3DVAR (SLA/T/S/SST)*
MOVE-C[w] MRI/JMA	Coupled DA	1° MRI.COM2 coupled	*3DVAR (SLA/T/S/SST)*
MOVE-G2[x] MRI/JMA	JRA-55 corr+Bulk	0.5°×1° MRI.COM3	*3DVAR (SLA/T/S/SST)*
MOVE-CORE[y,z] **MRI/JMA**	CORE.2 Bulk	0.5°×1° MRI.COM3	*3DVAR (T/S)*
SODA[aa] U. of Maryland and TAMU	ERA40 to 2002; ERAi thereafter. Bulk	1/4° POP2.1	*OI (T/S/SST)*
UR025.4[bb] U. of Reading	ERAi +CORE Bulk	1/4° NEMO3.2	*OI (SLA/T/S/SST/SIC)*
AVISO[cc] CLS	N/A	1/4° Obs-Only (SSH/SLA)	*OI (SLA)*
SICCI[dd] ESA	N/A	1/4° Obs-Only (SSH/SLA)	*OI (SSH)*

[a]Guinehut et al. 2012; [b]Mulet et al. 2012; [c]Saha et al. 2010; [d]Xue, 2011; [e]Storto et al. 2011; [f]Fukumori, 2002; [g]Wunsch & Heimbach, 2013; [h]Speer & Forget, 2013; [i]Ingleby & Huddleston, 2007; [j]Köhl, 2014; [k]Zhang et al. 2007; [l]Chang et al. 2013; [m]Blockley et al. 2013; [n]Waters et al. 2014, [o]Behringer, 2007; [p]Masuda et al. 2010; [q]Sugiura et al. 2008; [r]Meyssignac et al. 2012; [s]Levitus et al. 2012; [t]Yin et al; 2011; [u]Balmaseda et al. 2013; [v]Mogensen et al. 2012; [w]Fujii et al. 2009; [x]Toyoda et al. 2013; [y]Tsujino et al. 2011; [z]Danabasoglu et al. 2013; [aa]Carton & Giese, 2008; [bb]Haines et al. 2012; [cc][(http://www.aviso.oceanobs.com/fileadmin/documents/data/tools/hdbk_duacs.pdf]; [dd]Ablain et al. 2013.

Sea ice in atmospheric reanalyses

From Lindsay et al., 2014, Journal of Climate.

TABLE 2. Reanalysis product characteristics.

Reanalysis	NCEP-R1	NCEP-R2	CFSR	20CR	MERRA	ERA-Interim	JRA-25
Time interval	1948–present	1979–present	1979–present	1871–2008	1979–present	1979–present	1979–present
Type	Spectral	Spectral	Spectral	Spectral	Finite volume	Spectral	Spectral
Spatial resolution	T62 (210 km)	T62 (210 km)	T382 (38 km)	T62 (210 km)	0.5° × 0.66° (65 km)	T255 (79 km)	T106 (120 km)
Vertical levels (top pressure)	Sigma, 28 (3 hPa)	Hybrid sigma, 28 (3 hPa)	Hybrid sigma, 64 (0.26 hPa)	Hybrid sigma, 28 (0.2 hPa)	Hybrid sigma, 72 (0.1 hPa)	Hybrid sigma, 60 (0.1 hPa)	Hybrid sigma, 40 (0.4 hPa)
Data assimilation method	3D-Var	3D-Var	3D-Var	Ensemble Kalman filter	3D-Var/IAU	4D-Var	3D-Var
Sea ice and SST	Various prescribed	AMIP-II prescribed	Various interactive	HadISST prescribed	Reynolds prescribed	NCEP* prescribed	SMMR and SSM/I prescribed

* NCEP refers here to a changing suite of operational sources from the National Centers for Environmental Prediction.