DRAKKAR Ocean Modelling Program

Intrinsic and forced low-frequency variability in the eddying ocean (observations, simulations and processes)

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1 OBSERVATIONS + climate studies

- 7-8 year variability in the NAO and climate records in the North Atlantic (i.e. slower than ENSO-induced variability)

(Plaut and Vautard, 1994; Da Costa & Colin de Verdière, 2002)

- Interannual-to-decadal SST/SSH variability within the Gulf Stream extension ➔

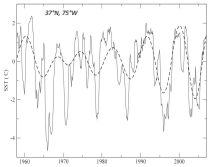
(Feliks et al, 2011)

- This SST variability likely to emerge in the ocean & modulate atmosphere

(Feliks et al, 2011)

- The ocean *drives* the atmospheric variability in frontal zones and over eddies

(Small et al, 2008) i.e. presumably also away from the North Atlantic (e.g. ACC)



➔ **Origin of low-frequency intrinsic ocean variability ? Implications for atmospheric prediction ?**

2 IDEALIZED OCEAN MODELS + constant forcing (QG/SW, box/channel, sinus wind)

Mesoscale eddies and/or high *Re* numbers ➔ chaotic intrinsic 1-10 year variability in eddying regions

(e.g. Jiang et al. '95, McCalpin & Haidvogel '96, Dijkstra and Ghil '05, etc)

- Small nonlinearities - bifurcations between stable equilibria

Dynamical Systems Theory (Dijkstra and Ghil '95), Multiplicative noise (Sura '10)

- Strong nonlinearities - eddy-driven processes

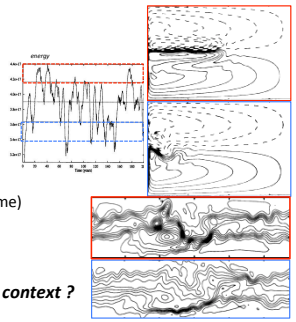
Temporal inverse cascade (Arbic '11), Reynolds stresses (Berloff et al '07)

➔ GS/Kuroshio, ACC (path, transport)

Mean vs. eddy PV advection (Dewar '03; Spall '96) + topog. (Hogg & Blundell '06)

➔ recirculation gyres (shape, strength) & mode waters (thickness, volume)

Mean vs. low-freq PV advection (Hazeleger & Drijfhout '00)



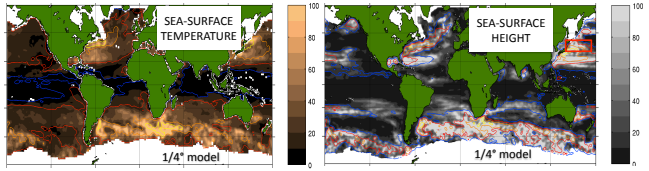
➔ **Origin of intrinsic variability**
➔ **Which distribution/patterns/magnitude** | ***in global, realistic context ?***

3 OGCMs with seasonal forcing (only a few studies so far)

- Intrinsic, chaotic variabilities **of global SLA** (*Penduff et al '11*) **and global SST**

1/4° global NEMO : Comparison of AVISO, fully-forced run, seasonally-forced run
These results for SLA are very close to 1/10° OFES in Kuroshio (Taguchi et al '07), and to 1/12° NEMO in North Atl (unpublished).

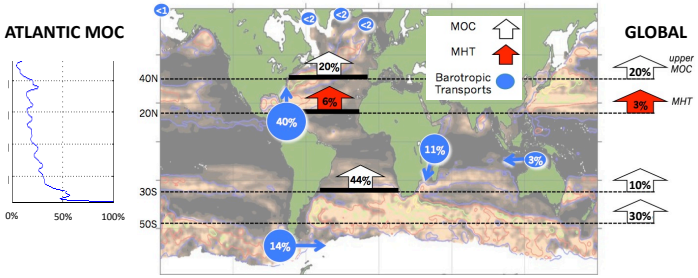
Percentage of intrinsic variance in the total interannual variances of SST and SLA :
- up to 70-100% locally
- in eddy-active areas
- none at 2° resolution



- Intrinsic, chaotic variability of **inter-gyre heat transport** in the eddying North Atlantic (*Hall et al '04*)

1/6° Atlantic OPA : Largely dominates the atmospherically-forced component

- Percentage of intrinsic variance in the total interannual variance of **MOC and transports** in NEMO 1/4°



• Large intrinsic AMOC variability due to Agulhas eddies (as in Biastoch et al, 2008)
• Secondary maximum around 40°N

• Florida Current transport variability is 40% intrinsic
• 14% at Drake passage

• Global MOC variability is: 30% intrinsic at 45°S
20% intrinsic at 40°N

➔ **4D features ? Origin and dynamics ? Imprint on climate indices ? Imprint on observations ?**
➔ **Consequences of this low-frequency « noise » for ocean monitoring/hindcasting/prediction ?**

INTRINSIC 1-10 YEAR VARIABILITY in the realistic ocean

What's known, what's not ?

- Idealized models (many dynamical/statistical studies) ➔ interann. variability is produced without interann. forcing.
- OGCMs: interann. intrinsic var. is absent at 2° (IPCC-like), but simulated when & where eddies are (1/4° resol. is OK)
- Strong evidence that SSH/SST low-freq observed variabilities are largely intrinsic (Gulf Stream, ACC, Kuroshio, etc)
- Intrinsic variability very likely to affect all observations, and climate predictions with eddying ocean models
- ...but intrinsic variability is very poorly known in realistic context, e.g.:
- **(1) Imprint on other satellite/in-situ observations ? On climate indices ? Spectral features ?**
- **(2) Subsurface structure ? Dynamics ? How does mesoscale features feed low-frequency variability ?**

4 *Next steps*

- **The US/EU Chaocean project will be submitted to the next OST/ST to address issues listed on the left**
- Observational/operational issues (1) investigated at global scale — Dynamical issues (2) in the North Atlantic
- Team of 13 dynamicists, statisticians, OGCM modellers, observationalists
- Idealized simulations ←→ OGCM hi-res simulations ←→ observations ←→ statistical/physical diagnostics
- Hierarchy of seasonally-/interannually forced simulations
  - NEMO and HYCOM OGCMs : ensemble of long, global 1/4° simulations (+ 1/12° global simulations)
  - MIT OGCM : North Atlantic 1/12° and 1/36°
  - 1-10km QG models : process studies
- Observational imprints studied from synthetic obs (simulations subsampled as satellite/in-situ observations)
- Joint analysis of model hierarchy : EOFs, CCA, MSSA, PV budgets, spectral analyses, etc

References

- Arbic, B.K., R.B. Scott, G.R. Flierl, A.J. Morten, J.G. Richman, and J.F. Shriver, 2011: Nonlinear cascades of surface oceanic geostrophic kinetic energy in the frequency domain. In revision.
- Berloff, P.S., A.Mc.C. Hogg, and W.K. Dewar, 2007: The turbulent oscillator : a mechanism of low-frequency variability of the wind-driven ocean gyres. JPO, 37, 2363-2386.
- Biastoch, A., C. Böning, and J. Lutjeharms, 2008: Agulhas leakage dynamics affects decadal variability in Atlantic overturning circulation. Nature, 456, 489–492.
- Da Costa, E. D., and A. Colin de Verdière, 2002: The 7.7-year North Atlantic oscillation. Quart. J. Roy. Meteor. Soc., 128A, 797–817.
- Dewar, W.K., 2003: Nonlinear midlatitude ocean adjustment. J. Phys. Oceanogr., 33, 1057–1082.
- Dijkstra, H. A., and M. Ghil, 2005: Low-frequency variability of the large-scale ocean circulation: A dynamical systems approach. Rev. Geophys., 43, RG3002.
- Feliks, Y., M. Ghil, and A. W. Robertson, 2010: Oscillatory climate modes in the eastern Mediterranean and their synchronization with the NAO. J. Climate, 23, 4060–4079.
- Feliks, Y., M. Ghil, ans A.W. Robertson, 2011: The Atmospheric Circulation over the North Atlantic as Induced by the SST Field. J. Climate, 24, 522–542.
- Hall, N., B. Barnier, T. Penduff, and J.-M. Molines, 2004: Interannual variation of Gulf Stream heat transport in a high resolution model forced by reanalysis data. Climate Dyn., 23, 341–351
- Hazeleger, W., and S. Drijfhout, 2000: A model study on internally generated variability in subtropical mode water formation. J. Geophys. Res., 105, 13 965–13 979.
- Hogg, A. M., and J. Blundell, 2006: Interdecadal variability of the Southern Ocean. J. Phys. Oceanogr., 36, 1626–1645.
- Jiang, N., F.F. Jin, and M. Ghil, 1995: Multiple equilibria, periodic and aperiodic solutions in a wind-driven, double-gyre, shallow-water model. J. Phys. Oceanogr., 25, 764-786.
- McCalpin, J. D., and D. B. Haidvogel, 1996: Phenomenology of the low-frequency variability in a reduced-gravity, quasi-geostrophic double-gyre model. J. Phys. Oceanogr., 26, 739-752.
- Penduff, T., M. Juza, B. Barnier, J. Zika, W.K.Dewar, A.-M. Treguier, J.-M. Molines, and N. Audiffren, 2011: Sea-level expression of intrinsic and forced ocean variabilities at interannual time scales. Journal of Climate, in press.
- Plaut, G., and R. Vautard, 1994: Spells of low-frequency oscillations and weather regimes in the Northern Hemisphere. J. Atmos. Sci., 51, 210–236.
- Small, R. J., S. P. DeSzoeke, S. P. Xie, L. O'Neill, H. Seo, Q. Song, P. Cornillon, M. Spall and S. Minobe, 2008: Air-sea interaction over ocean fronts and eddies, Dyn. Atmos. Ocean. 45, 274–319.
- Spall, M., 1996: Dynamics of the Gulf Stream/deep western boundary current crossover. Part II: Low-frequency internal oscillations. J. Phys. Oceanogr., 26, 2169–2182.
- Sura, P., and S.T. Gille, 2010: Stochastic Dynamics of Sea Surface Height Variability, J. Phys. Oceanogr., 40, 1582-1596.
- Taguchi, B., S.-P. Xie, N. Schneider, M. Nonaka, H. Sasaki, and Y. Sasai, 2007: Decadal variability of the Kuroshio Extension: Observations and an eddy-resolving model hindcast. J. Cli- mate, 20, 2357–2377.