→ ATLANTIC FROM SPACE WORKSHOP

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National Oceanography Centre
Southampton, UK

Observing the Atlantic Meridional Overturning Circulation (AMOC) from Space

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Atlantic Meridional Overturning Circulation (AMOC)

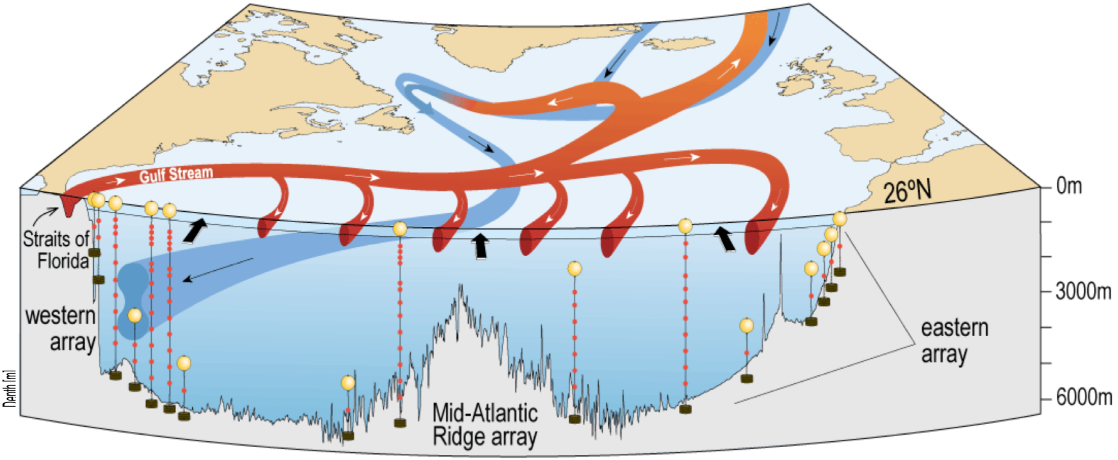
• Atlantic is unusual as MOC transports heat north across equator. Changes affect e.g.:

- SST in the N. Atlantic
- NW European weather+climate
- eastern US seaboard sea level
- rainfall in the Sahel
- hurricanes and monsoons
- CO_2 uptake+carbon transport / storage

• possibly through links with the Atlantic Multidecadal Variability (AMV/O oscillation)

• AMOC is predicted to slowdown or stop under global warming (cf. paleo record)

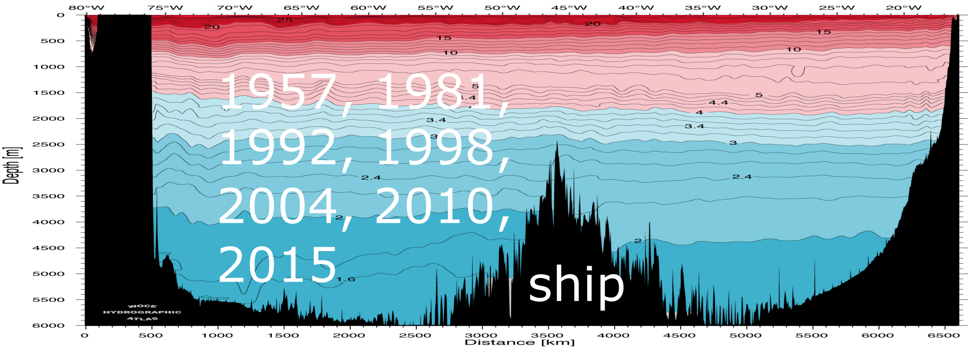
RAPID 26.5˚N and OSNAP arrays

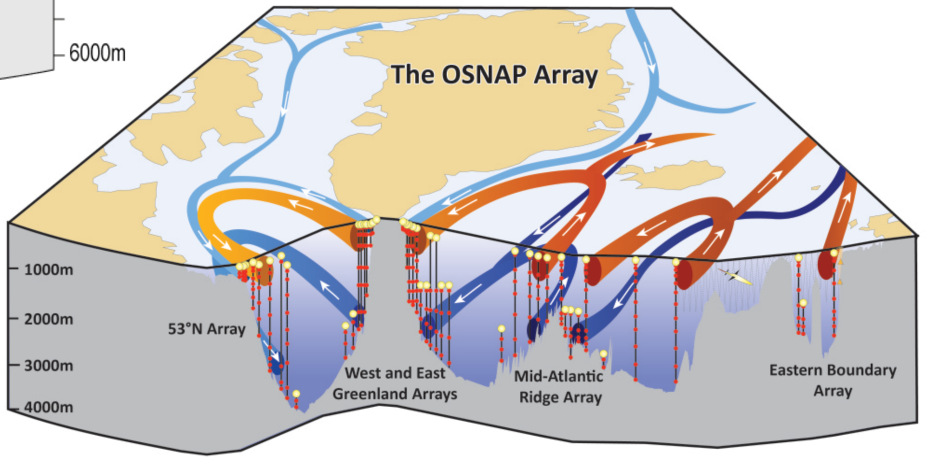


RAPID 26.5˚N from 2004

OSNAP from 2014

- presently both funded to 2020





How the AMOC is measured at 26.5°N

- AMOC at 26.5°N consists of 3 components:

  1) Ekman transport – from winds (satellite / re-analysis)

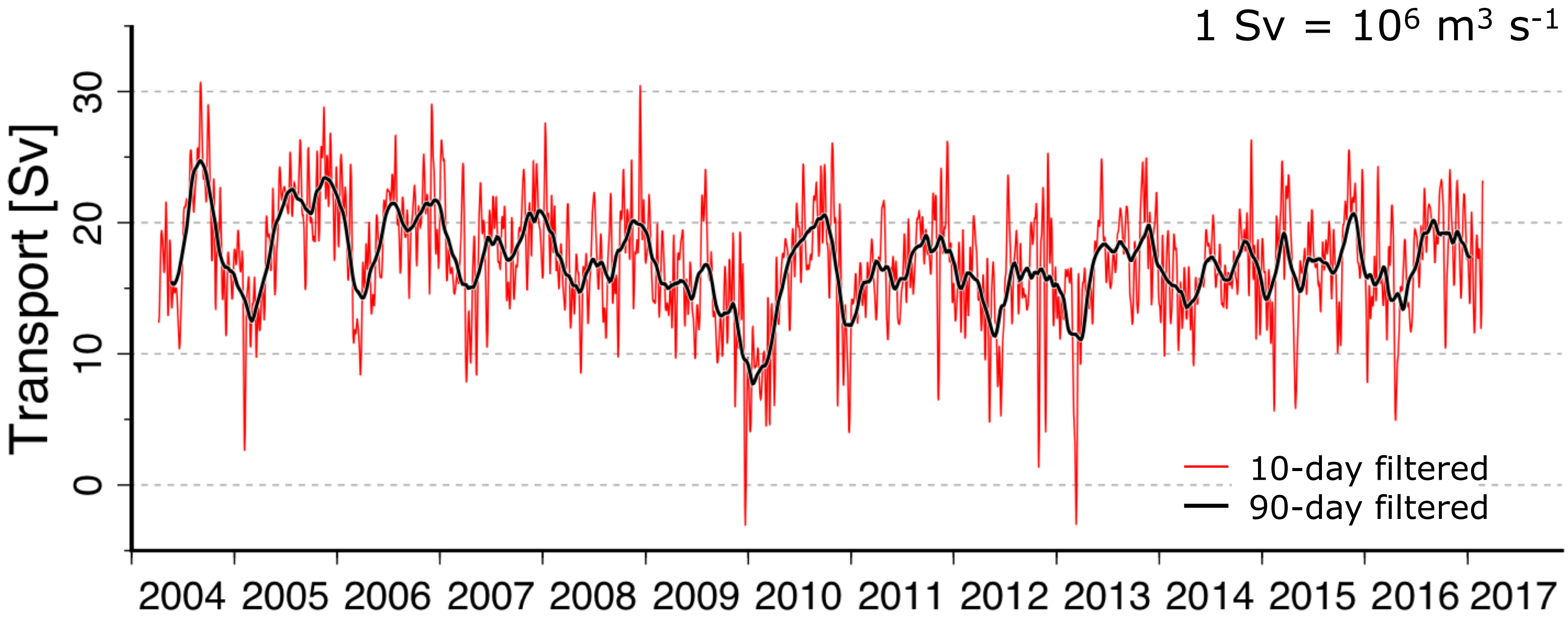
  2) Florida Straits transport – from calibrated cable measurements

  3) mid-ocean transport - from mooring array via geostrophy (upper ocean re-circulation + deep return flow) – linked via dynamic height / density to SLA

- in addition a zero net throughflow condition is imposed
- from these measurements an overturning stream function is calculated, which has a maximum at ~1100m, above which flow is northward and below southwards
- the 3 components of the northward flow, Ekman, Florida Straits and Upper Mid-Ocean (UMO), together give the strength of the AMOC

McCarthy, G. D. et al. 2015 Measuring the Atlantic Meridional Overturning Circulation at 26°N. Prog. Oceanogr. 130, doi:10.1016/j.pocean.2014.10.006

RAPID 26.5°N time series 2004-2017



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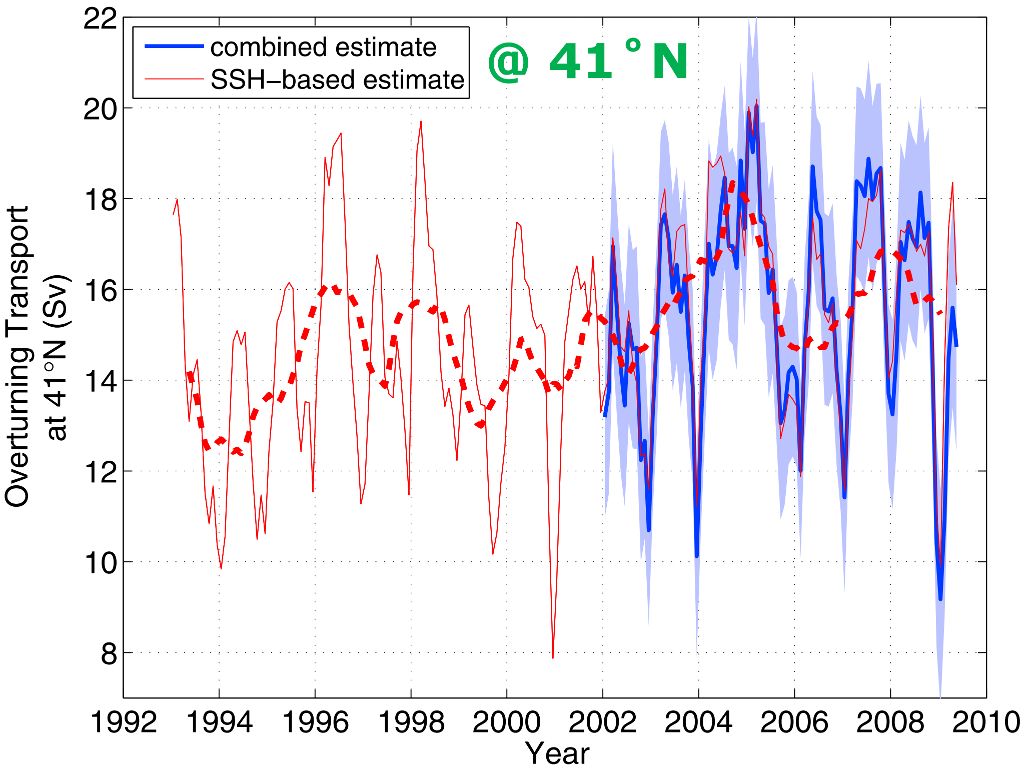
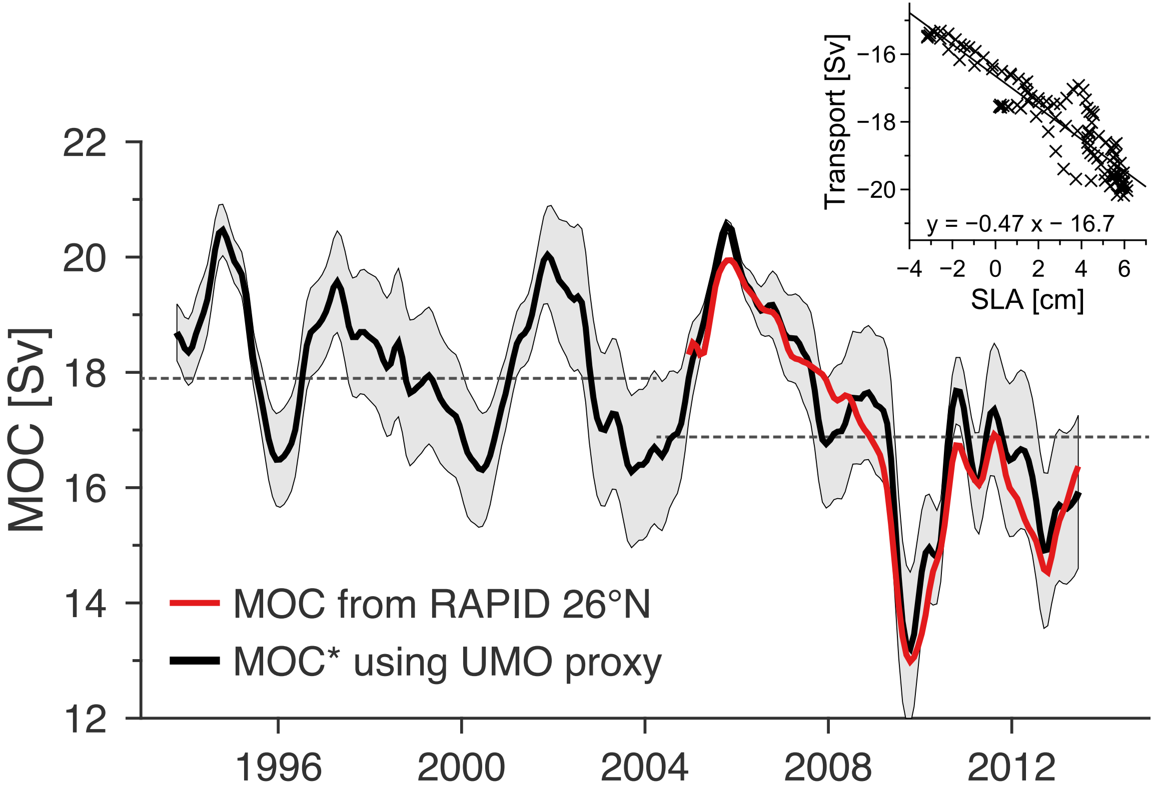
Satellite altimetry + Argo



- Argo used to estimate dynamic height at 1000m + T&S profiles for geostrophic shear to give 3-D absolute dynamic height from surface to 2000m
- Argo results regressed against altimeter SLA and upper 1000m transport calculated, Ekman added

Willis 2010 Can in situ floats and satellite altimeters detect long-term changes in the Atlantic Ocean overturning? *Geophys. Res. Lett.*, *37*, doi:10.1002/2010GL042372.

Satellite altimetry



- developed a SLA proxy for the 26.5°N UMO transport (over period of RAPID observations)
- combined with Florida Straits transport and Ekman transport from winds
- observations back to 1993

Frajka-Williams 2015 Estimating the Atlantic overturning at 26°N using satellite altimetry and cable measurements, *Geophys. Res. Lett.*, *42*, doi:10.1002/2015GL063220.

AMOC and bottom pressure

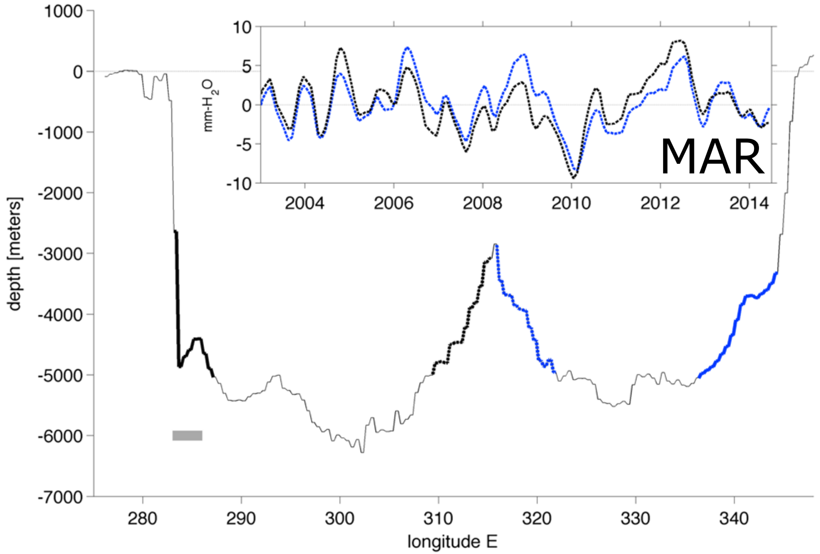
- Alternative formulation of AMOC: transport T(y) at latitude y over depth range (z1, z2) depends on the East-West pressure p(y, z) difference over that range (ρ_0 mean density, f Coriolis parameter)

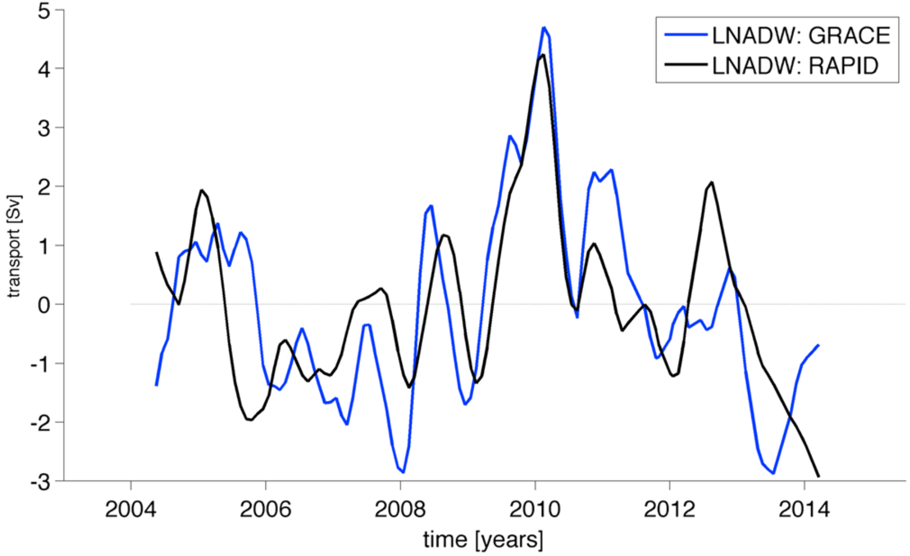
$$T(y) = \frac{1}{\rho_0 f} \int_{z1}^{z2} p_E(y,z) - p_W(y,z) dz.$$

- making sufficiently accurate *in situ* measurements of ocean bottom pressure (OBP) to directly apply the above equation is problematic

- GRACE gravimetry – measuring time-varying gravity – provides measurements of OBP anomalies (mm H_2O) from mascon gravity fields

AMOC from Ocean Bottom Pressure (OBP)





Landerer et al. 2015 North Atlantic meridional overturning circulation variations from GRACE ocean bottom pressure anomalies, Geophys. Res. Lett., 42, doi:10.1002/ 2015GL065730.

Figure 3. Meridional transport estimates from GRACE OBP anomalies on the eastern and western margin integrated over the 3000–5000 m depth layer at 26.5N, compared to the RAPID-MOCHA estimate of LNADW. The RMS difference between these two estimates is 1.2 Sv and the correlation is $R = 0.69$. The 1 sigma error of the GRACE-LNADW estimate is ±1.1 Sv.

Some other studies

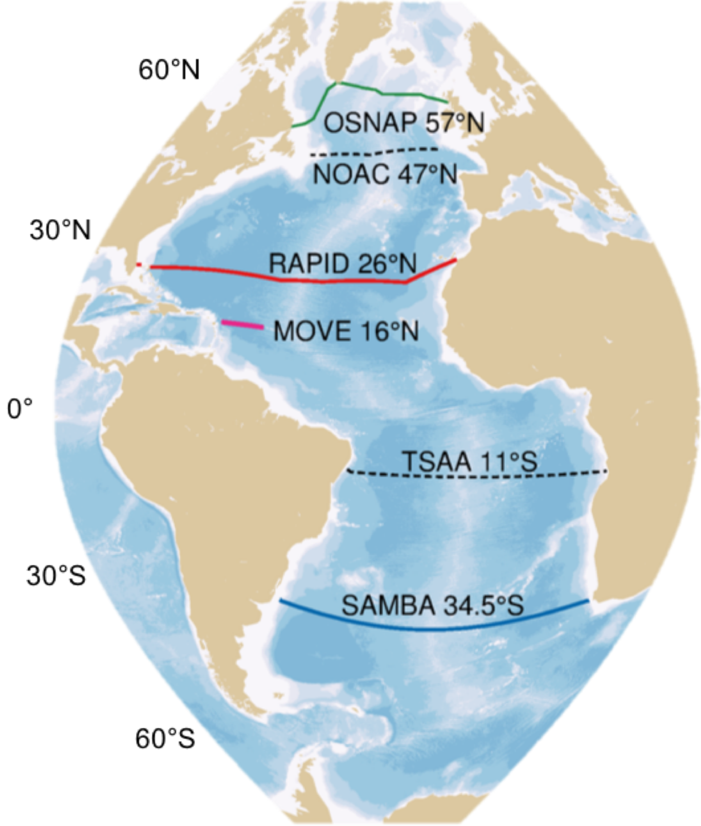
- Mercier et al. (2015, Prog. Oceanogr.) – altimetry, Argo, hydrography to reconstruct AMOC (in density space) along Greenland-Portugal OVIDE section
- Dong et al. (2015, GRL) – synthetic T & S profile from altimetry SLA (based on correlations) to give variability of SAMOC between 20°S and 35°S
- Majumder et al. (2016, JGR) – Argo and altimeter sea surface height to construct 3-D velocity field and hence estimate AMOC at 20°, 25°, 30° and 35°S.
- Worthington et al (2019, JGR) – GRACE OBP and *in situ* BP for deep overturning variability at 26.5°N

- at this meeting, see poster by Frajka-Williams et al. on AMOC from altimetry and gravimetry – how best to combine altimetry and gravimetry to estimate the AMOC

Limitations

- altimetry + Argo – only feasible where major flows are in water of depth 2000m or more => restricted latitudinally ~39°- 45°N in N. Atlantic
- altimetry – relationships between sea level anomalies and dynamic height and T & S may change on longer timescales as water mass properties vary
- gravimetry – uncertainties at longer timescales due need to correct for glacial isostatic adjustment (removal of trend), effect of land hydrology on measurements near coasts, plus coarse spatial resolution (3°)
- satellite AMOC estimates provided typically at monthly time resolution
- problem affecting all satellite AMOC measurements is that of validation and verification over decadal times scales
- can only be sure of satellite determined AMOC measurements by comparison with *in situ* direct observations

Observing AMOC – future requirements



- key question: AMOC meridional coherence
- new *in situ* observing systems being deployed (RAPID 26.5°N time series from 2004)
- altimetry (sea surface height / level) and gravimetry (OBP) can help "join the dots"
- challenge: how best to combine observations?
- scatterometry and passive microwave contribute to wind information (=> Ekman)
- infrared SST and passive microwave SST & SSS for links to AMV and air-sea interactions
- altimetry for coastal sea level
- challenge – to characterise AMOC impacts

Observing the AMOC from Space - conclusions

- Observing the AMOC, determining its meridional coherence, how it is changing over long times scales (decades), and the consequent impacts (weather, climate, sea level), is a challenging problem.
- Satellite observations of winds, sea level / sea surface height, ocean bottom pressure, SSS & SST can all contribute.
- The overarching challenge is to build a sustained observing system.

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