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Driving the ocean circulation

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WOC (ESA-ESRIN) in Frascati, 21-22 February 2019

Errors in Ocean Forcing

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- Atmospheric model data are used for ocean forcing
- ERAint and ERA5 10m stress-equivalent winds (w.r.t. earth frame)
- CMEMS ASCAT Level-3 REP observed ocean-current-relative wind data
- Wind-related ocean drifts are part of scatterometer (and ERA) winds
- Trial with ocean current correction (Globcurrent) of ERA to make it ocean-relative
- Differences:
  - Zonal and meridional mean wind
  - Zonal and meridional transient wind
  - WIND Stress curl
  - Wind divergence
- Differences mainly reveal ERA errors since ASCAT errors are small

Zonal, Meridional Errors

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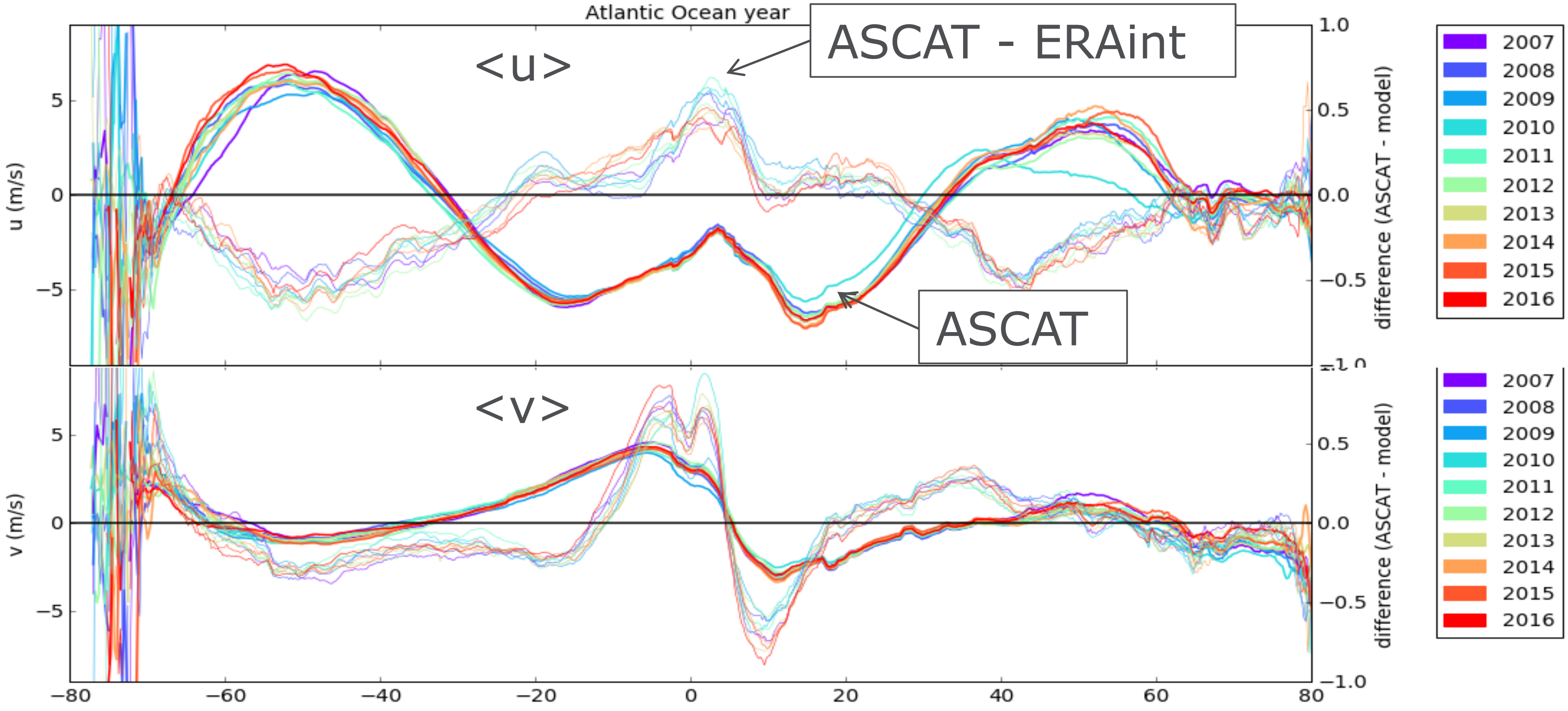
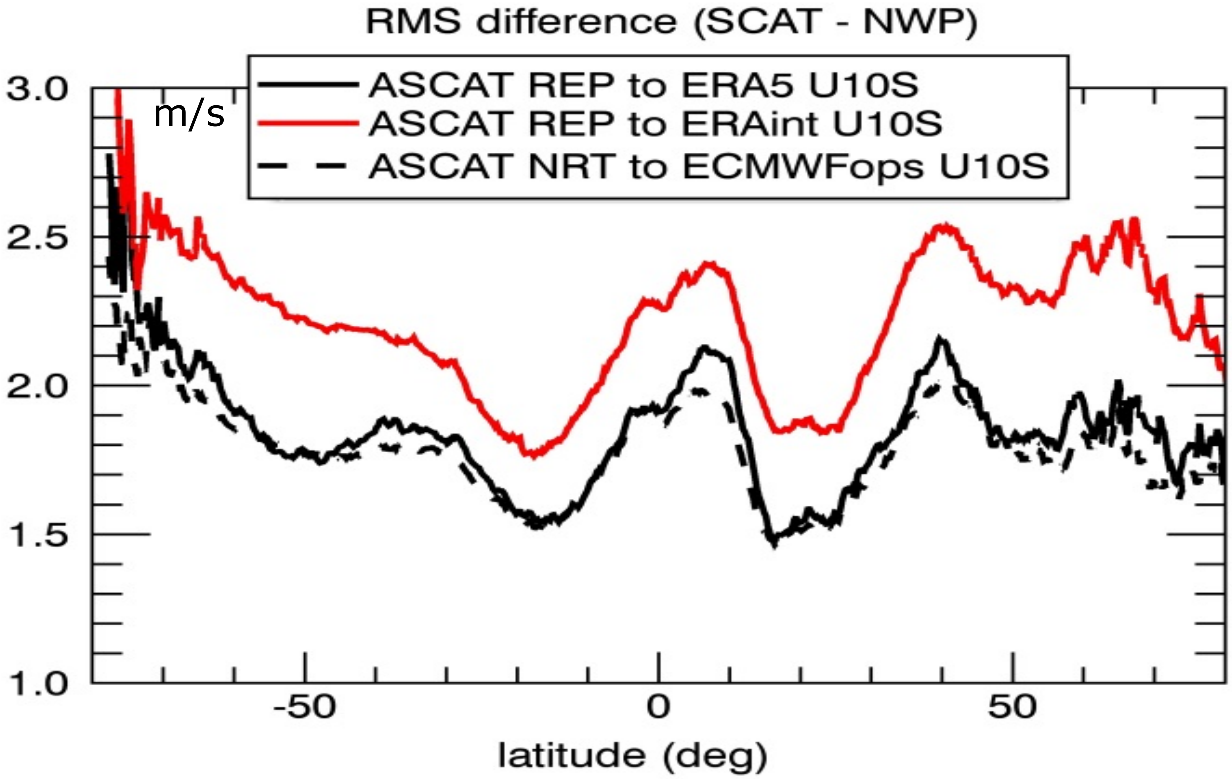


→ Systematic errors are larger than interannual variability

ERA-interim vs. ERA5

- → ERA5 similar to OPS
- → ERA-interim has ~20% larger RMS wind speed differences



Zonal, Meridional Errors

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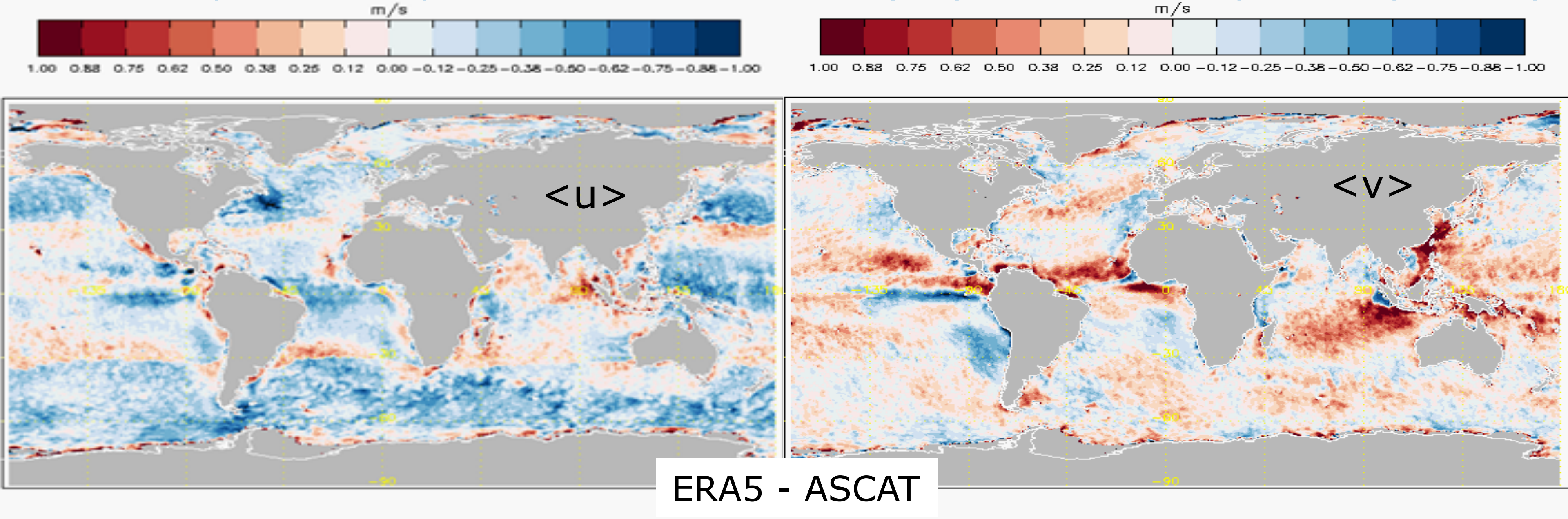
ERA5 has spatial error patterns similar to ERAint (only reduced in amplitude by ~20%)



→ Excess mean <u>model</u> zonal winds (blues at mid-latitudes and subtropics)

→ Defective mean <u>model</u> meridional winds (reds at mid-lats and tropics)

Model Wind Errors

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Underestimation of wind turning in NWP model: surface winds more aligned to geostrophic balance above than to pressure gradient below → stable model winds are more zonal with reduced meridional flows

Sandu (ECMWF) reports that turbulent diffusion is too large (enlarged to reduce sub-grid mesoscale variability) which helps improve the representation of synoptic cyclone development at the expense of reducing the ageostrophic wind turning angle ...

→ It is a problem that the ocean is forced in the wrong direction though

Other processes poorly represented include 3D turbulence on scales below 500 km and wide-spread wind downbursts in (tropical) moist convection

→ Atmospheric mesoscale variability stirs the ocean and enhances fluxes

Transient Wind Errors

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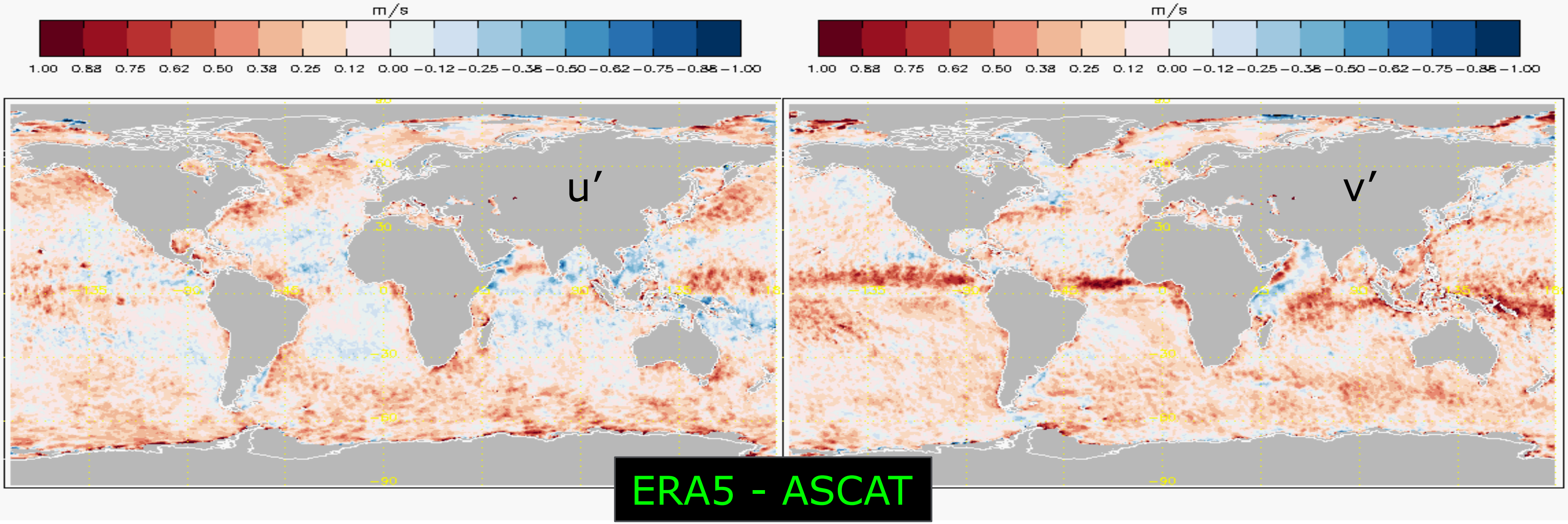

→ Defective <u>model</u> wind variability overall:

- Zonal (left) and meridional (right) at mid-to-high latitudes
- Particularly meridional deficit along ITCZ
- Locally enhanced along WBCs (ARC, ACC, GS, KE currents)

Wind Stress Curl

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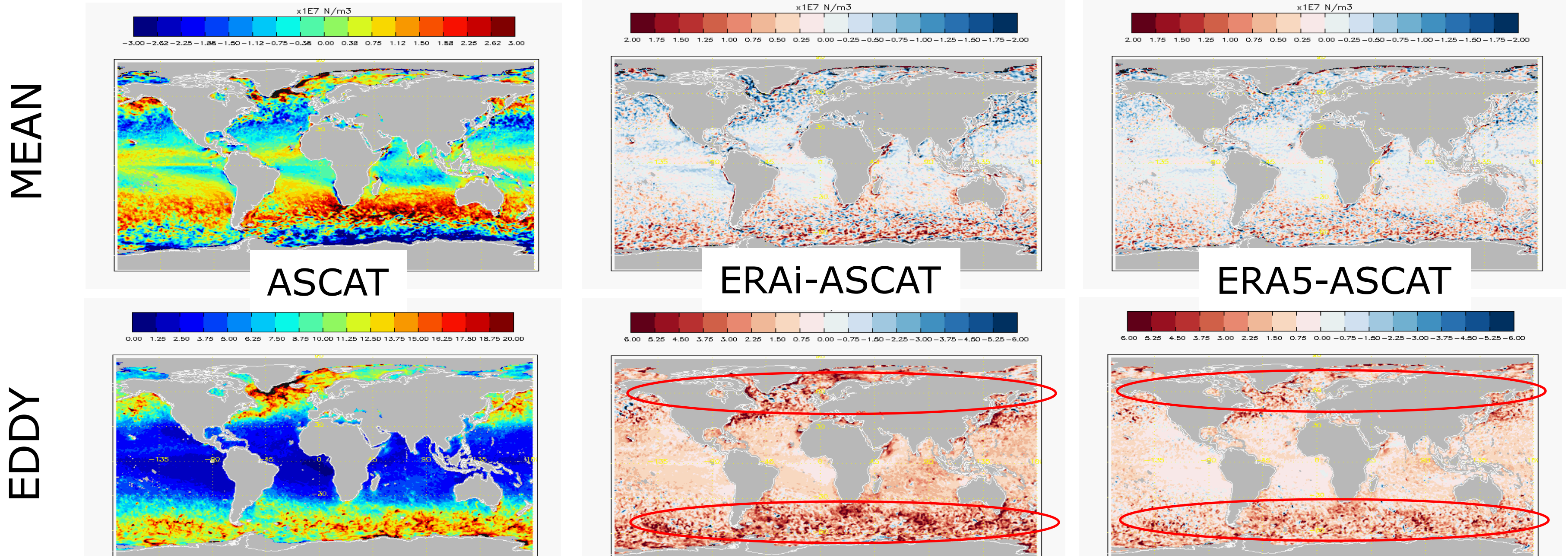

→ ERA mean stress curl is **more cyclonic** (blue NH, red SH) at high latitudes
→ May be caused by defective poleward meridional transport
→ Associated to low eddy stress curl activity → missing mesoscale turbulence
→ **This has obvious implications for Ekman upwelling estimates**

Wind Divergence Errors

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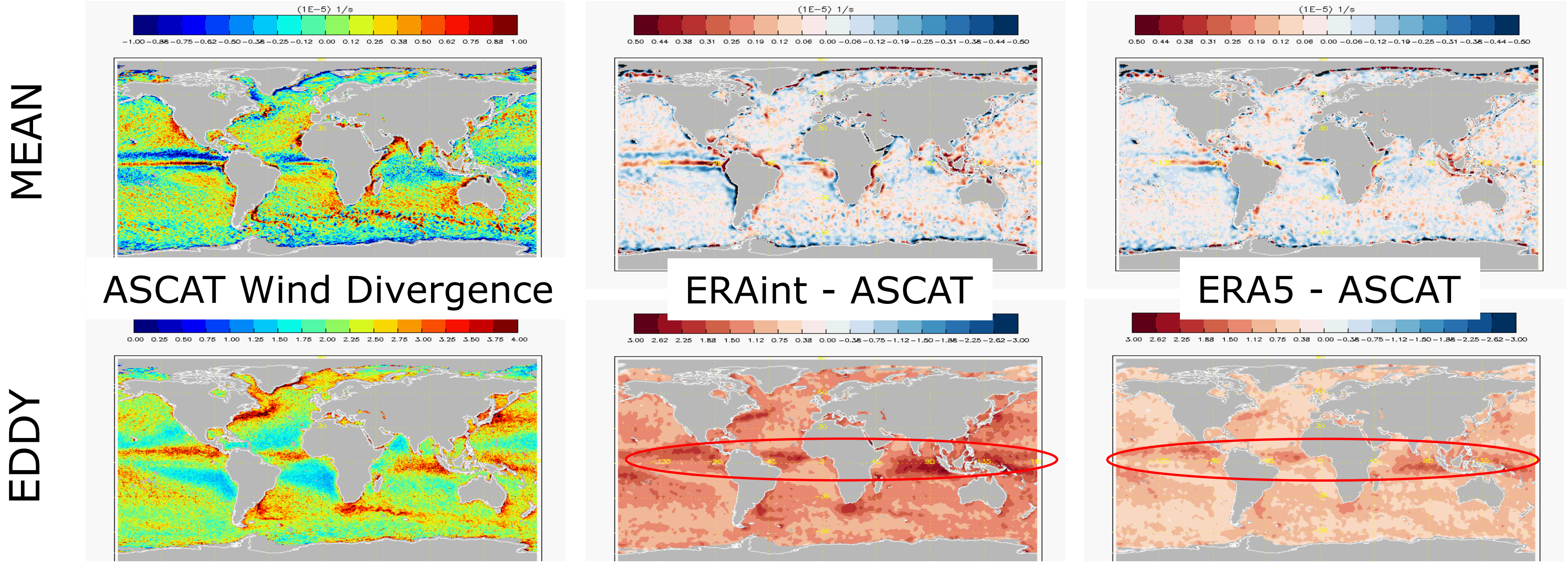
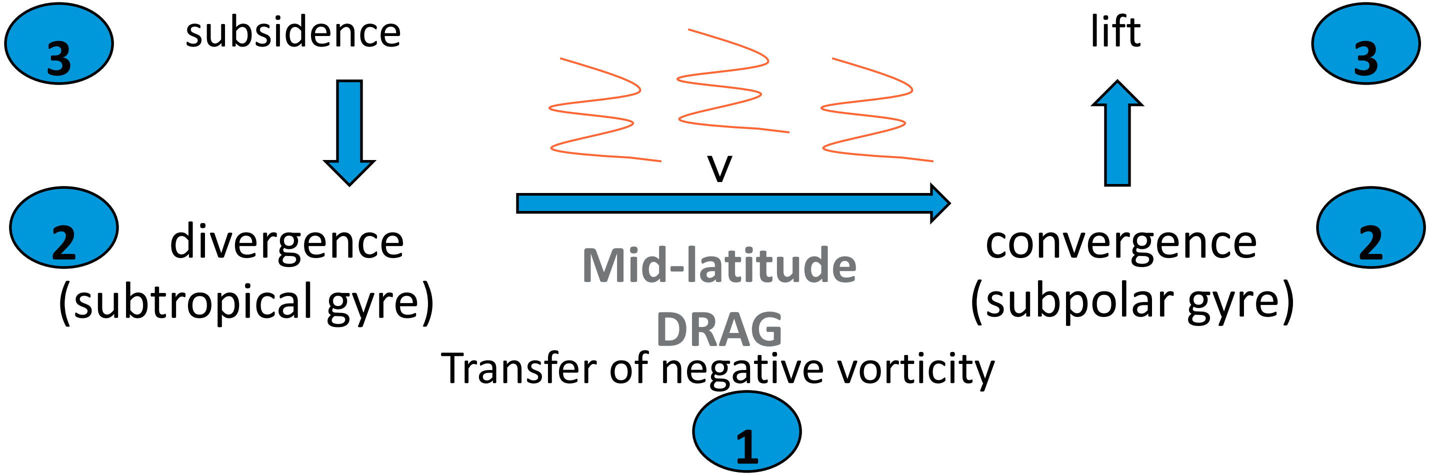


- → Defective model convergence along ITCZ, weak Pacific cold tongue divergence
- → Missing model mean divergence (subsidence) over subtropics (red)
- → Missing model mean convergence over subpolar area (blue)
- → Lacking tropical moist convection in eddy divergence

Error Mechanism ?

At **mid-latitudes**, missing wind variability in ERA can be associated to:

- Excess zonal mean model winds and defective poleward flows
- Excess cyclonic stress curl
- Defective subtropical divergence and defective subpolar convergence



→ Missing 3D turbulence weakens (poleward) flow in Ferrel Cell
→ Ocean forcing implications?

Belmonte Rivas & Stoffelen, 2019

Effect of Globcurrent

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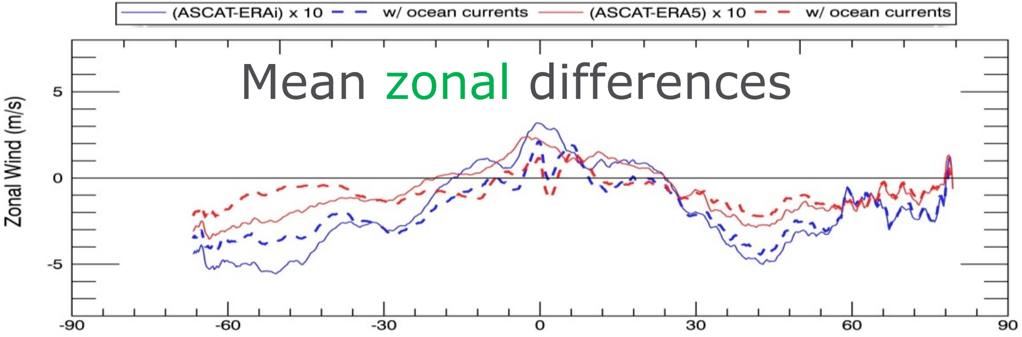
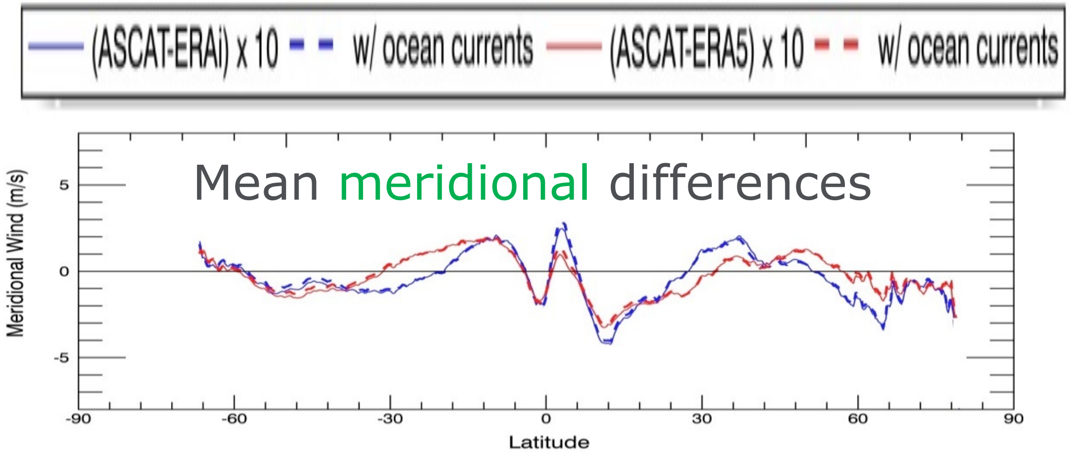
→ Globcurrent notably relieves the zonal wind biases



→ Globcurrent has no effect on the smaller meridional wind biases



Effect of Globcurrent

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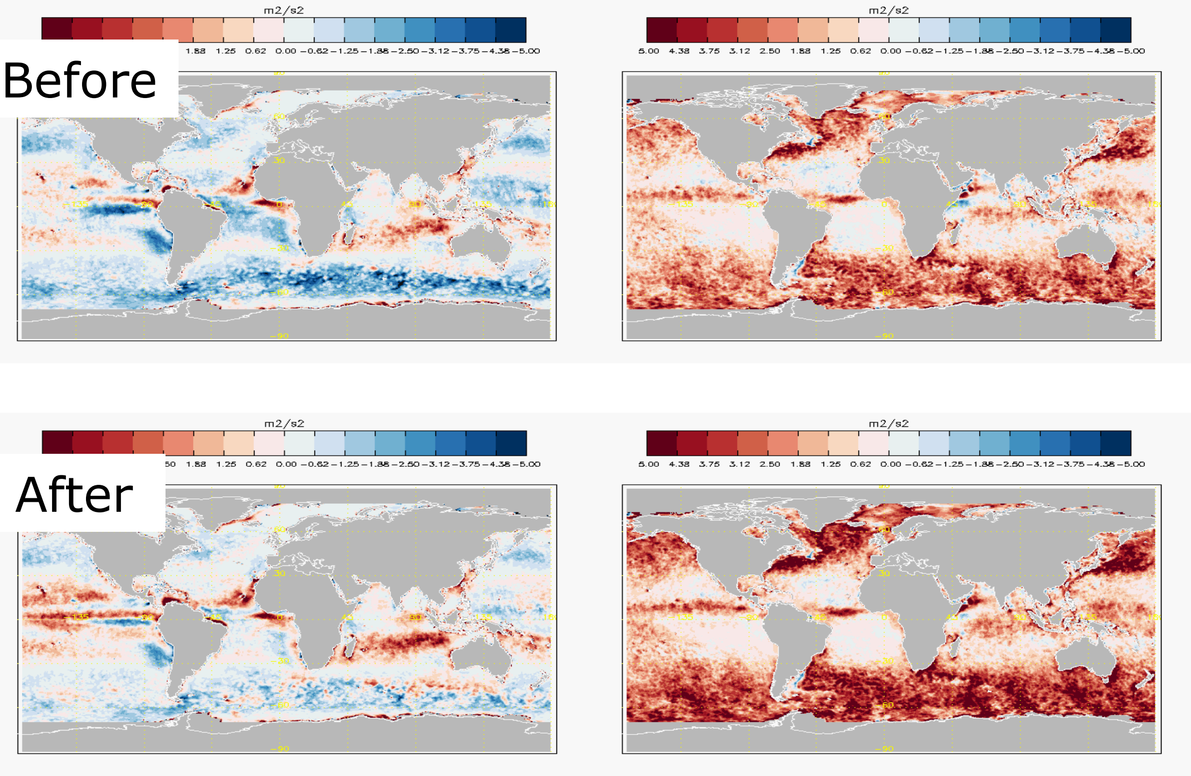
- → Reduces MKE differences in the mid-latitudes, but more red in tropics
- → EKE differences increase globally, particularly in the extra-tropics
- → Globcurrent mesoscales add variability to ASCAT differences
- → Local wind-related drifts are both in ASCAT and Globcurrent: double penalty



MKE differences EKE differences

Effect of Globcurrent

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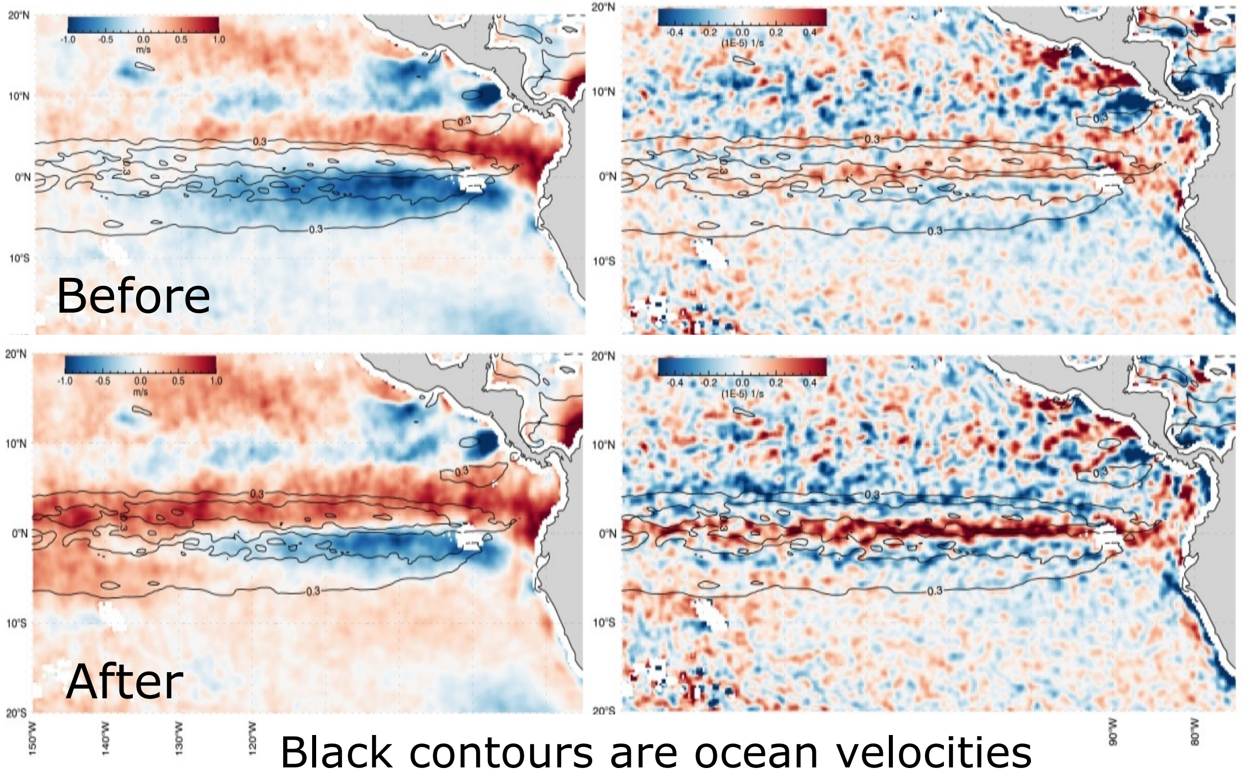
Eastern Tropical Pacific

→ Globcurrent accentuates SST effects in ASCAT winds that are missing in ECMWF winds

→ Provides much better alignment of ECMWF discrepancies with branched SEC (N and S) to show positive curl error in between



Black contours are ocean velocities

Mean wind speed differences to ERA5

Mean wind stress curl differences to ERA5

Conclusions

- ERA5 winds 20% better than ERA-interim and similar to OPS, yet show (extremely) systematic biases in both the partitioning into mean and transient, zonal and meridional winds
- At mid-latitudes, missing eddy/transient wind activity (missing mesoscale turbulence) can be related to defective poleward model transport – probably connected to residual Ferrel circulation
- In the tropics, missing eddy/transient wind activity (missing mesoscale convection) can be related to defective equatorward model transport – probably connected to residual Hadley circulation
- The ocean current correction contributes notably: relieves the zonal mean wind biases globally, but enhances differences connected with SST gradient effects over the equatorial cold tongues and WBC jets

➢ The remaining systematic and random errors should be accounted for to benefit atmospheric wind data assimilation, fluxes and the forcing of ocean models

Missing mesoscale variability in reanalyses

Surface wind stress and the associated heat and momentum fluxes play an important role in driving surface and deep ocean circulation

The inability of reanalyses to reproduce mesoscale variability implies underestimation of atmospheric forcing at the air-sea boundary, with detrimental consequences for ocean forcing [Condron, "polar mesocyclones", JGR, 2008] [Laffineur et al, "polar lows ERA interim", MWR, 2014]

Mean and eddy kinetic energies

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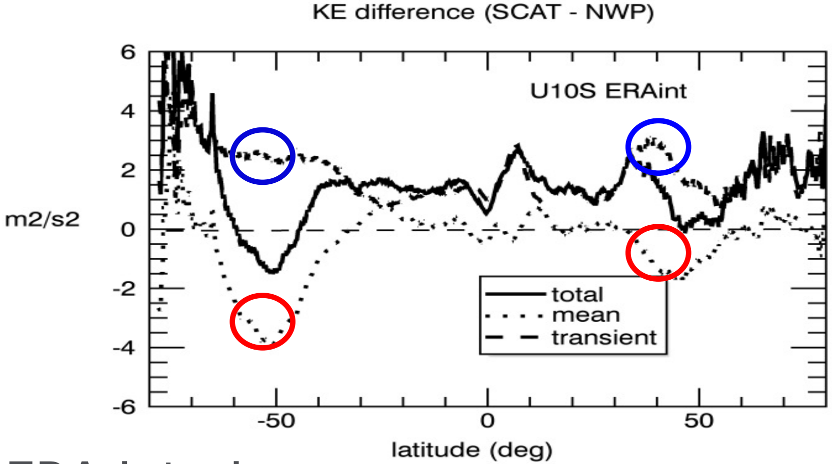
$u = \langle u \rangle + u'$

$v = \langle v \rangle + v'$

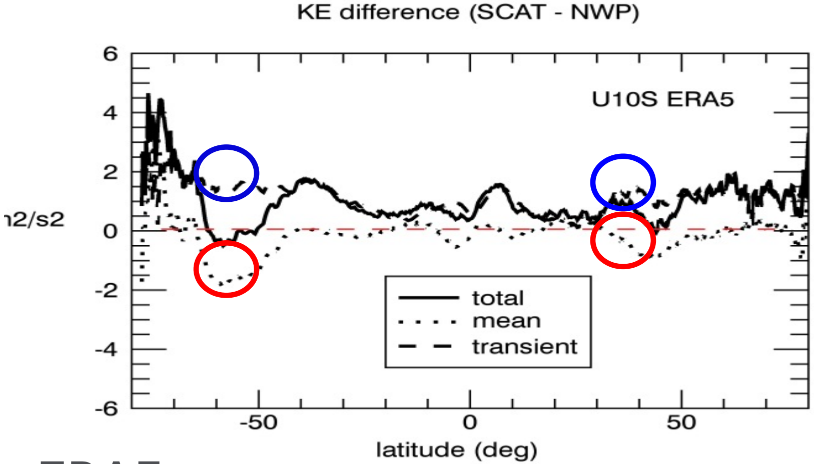
Average < > is over time (annual)

$$\text{TKE} = \text{MKE} + \text{EKE}$$

$$\langle u^2+v^2 \rangle \qquad \langle u \rangle^2+\langle v \rangle^2 \qquad \langle u'^2 \rangle+\langle v'^2 \rangle$$



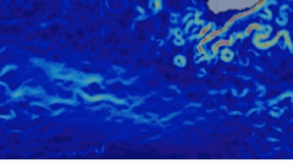
ERA interim



ERA5

→ ERA-int puts excess energy into mean flows and too little into eddies

→ In ERA5, mean flows have slowed down and eddy activity has increased



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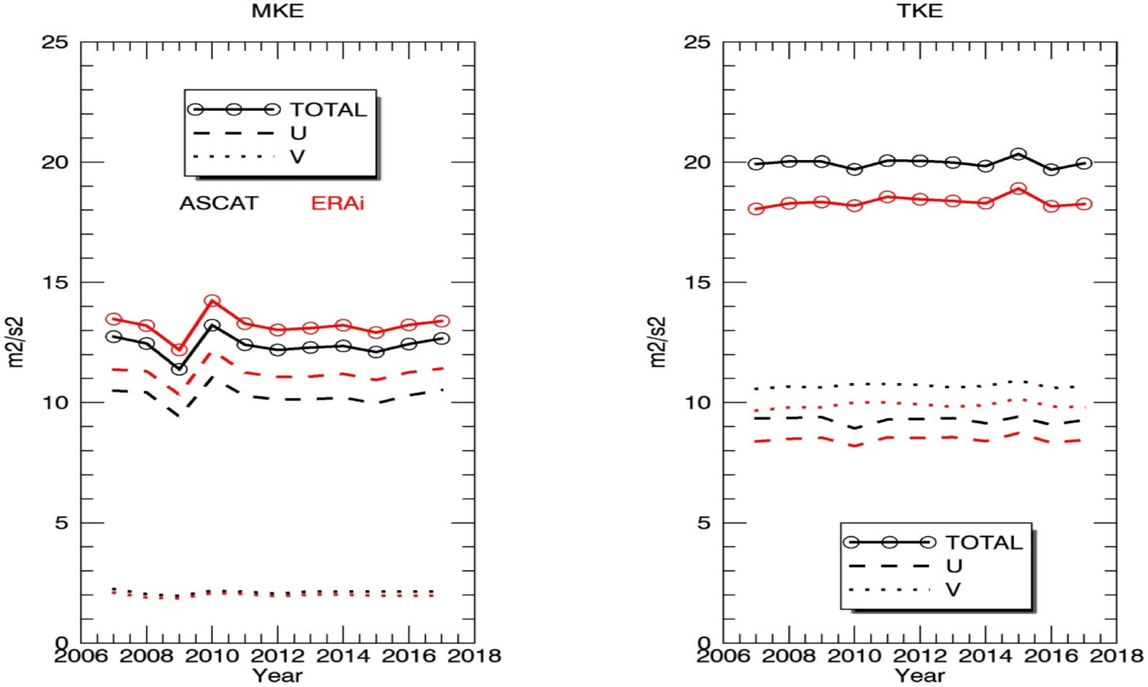
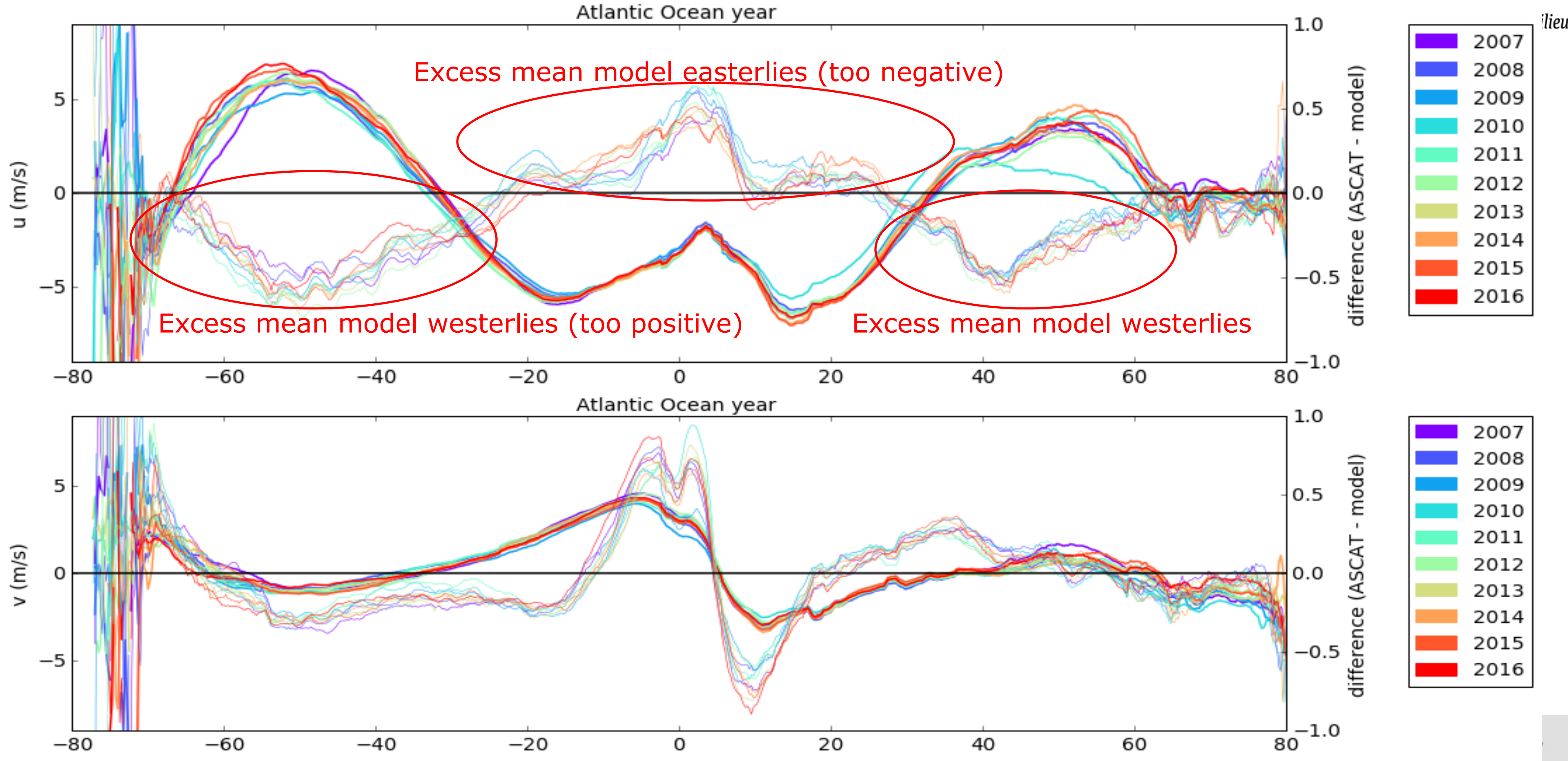


Figure 2.1.2: Time-series of globally averaged annual **mean kinetic energy** (MKE, left plot) and **turbulent kinetic energy** (TKE, right plot) contributions for the 2007-2017 period split into zonal and meridional components. The kinetic energy partition is shown for ASCAT observations (black) and ERA interim collocations (in red).

- On a global level, the ERA-int winds show that:
  - MKE is too high in the zonal, but low in the meridional
  - EKE is missing both in the zonal and meridional components

Zonal and meridional errors



Zonal and meridional errors

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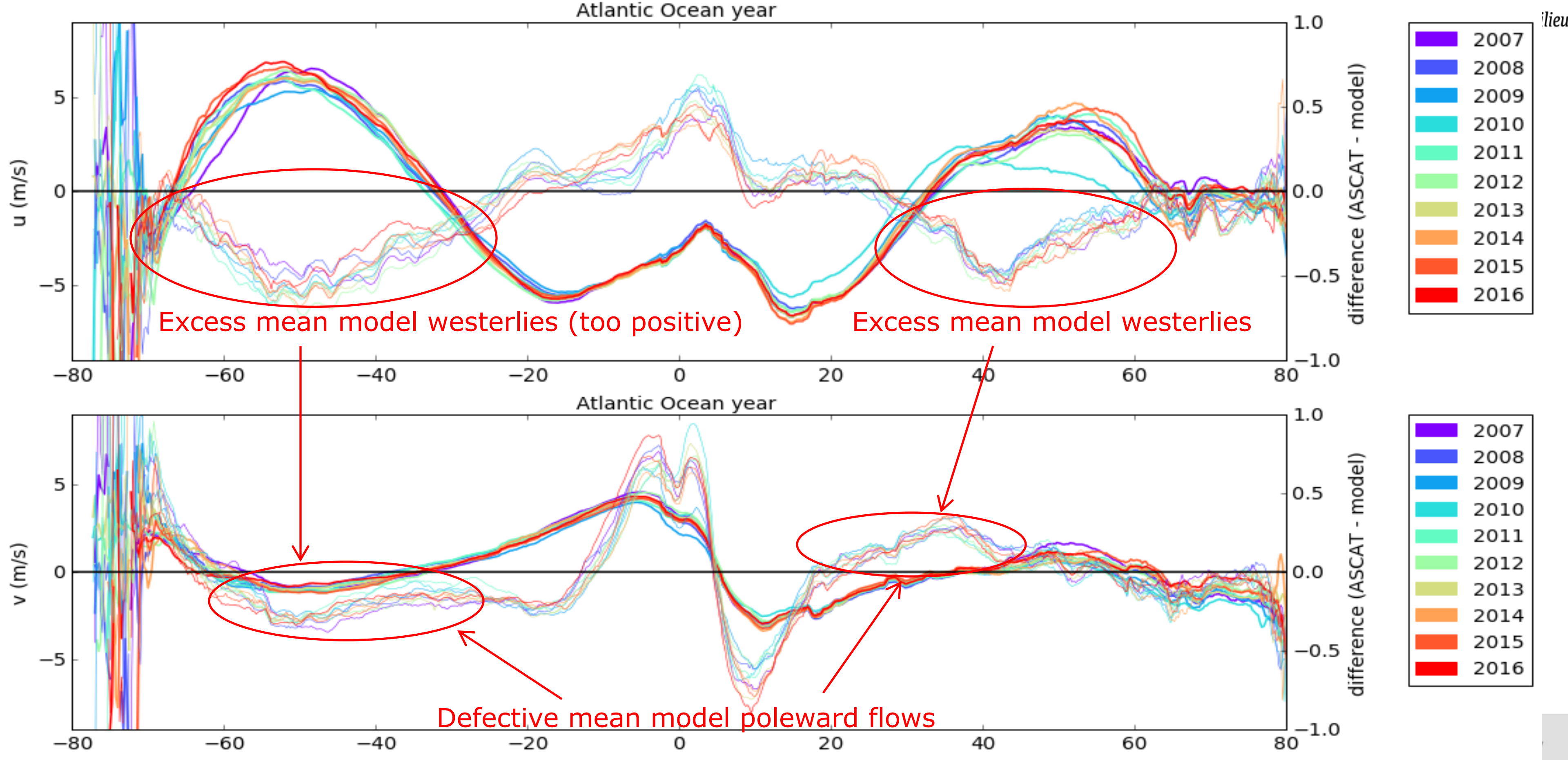

Zonal and meridional errors

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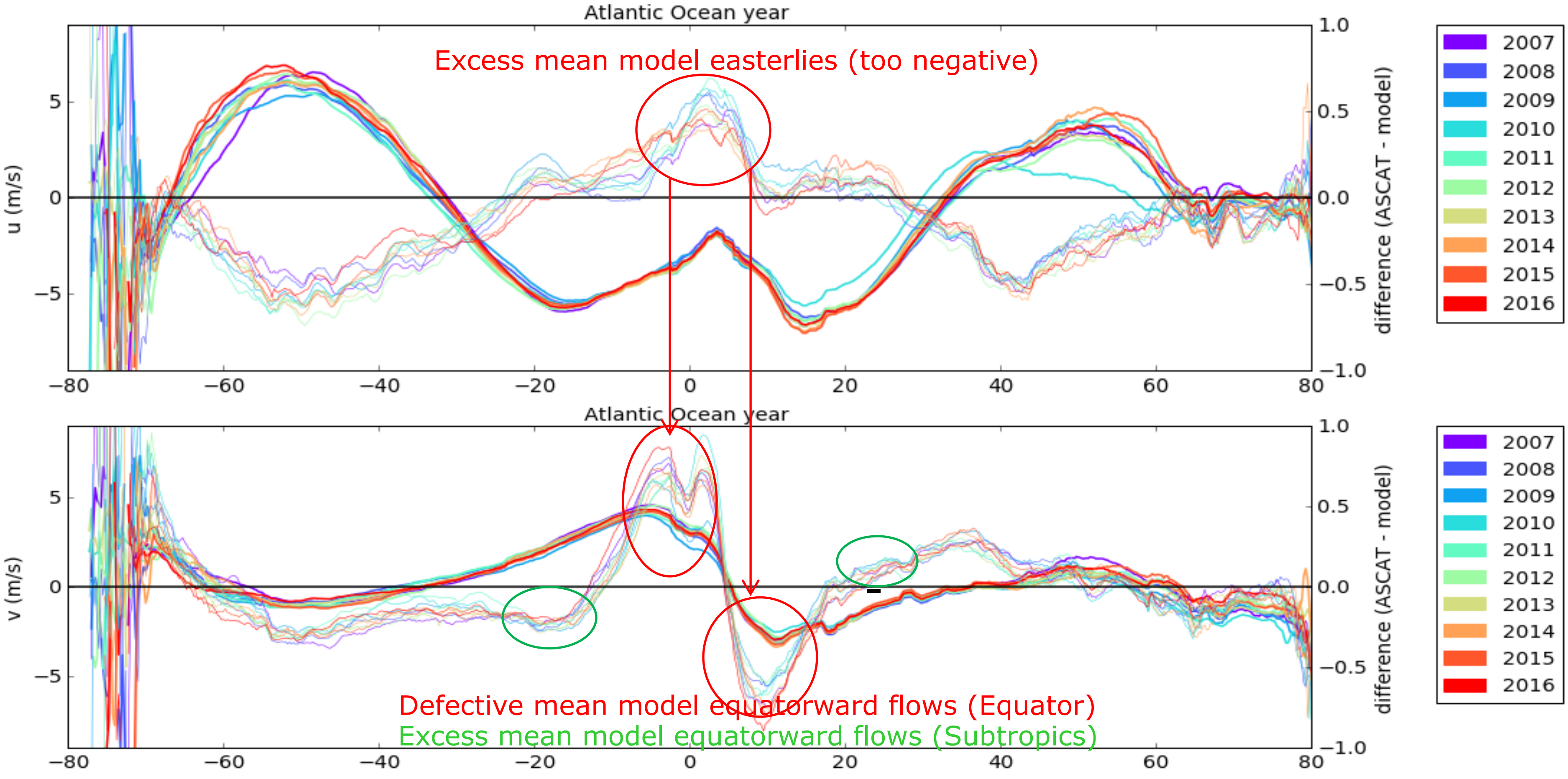

Zonal and meridional errors

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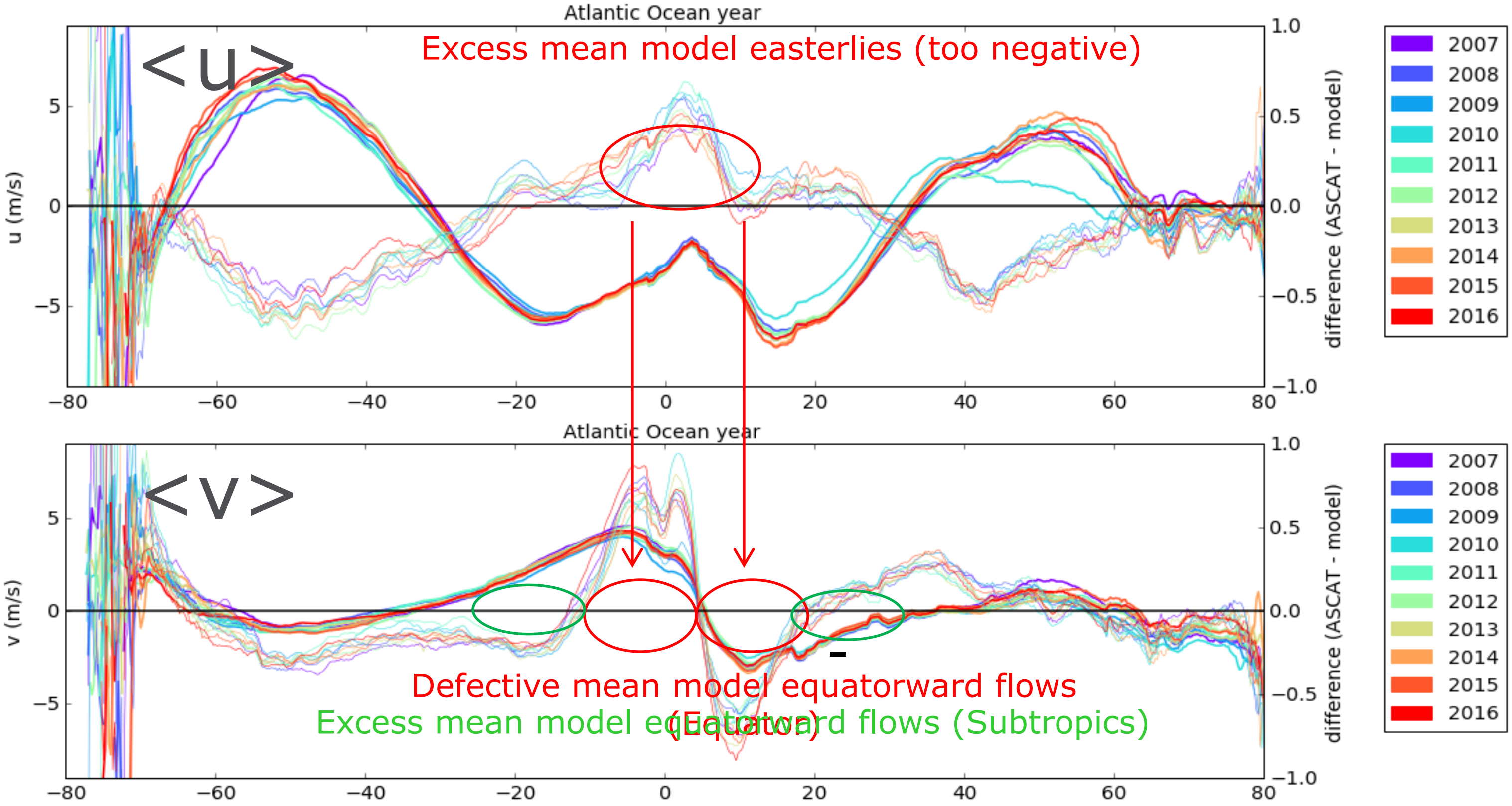
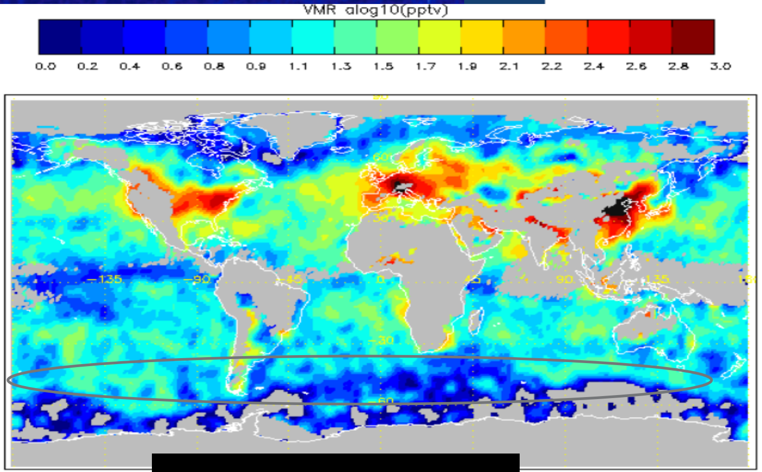


ITCZ convergence??

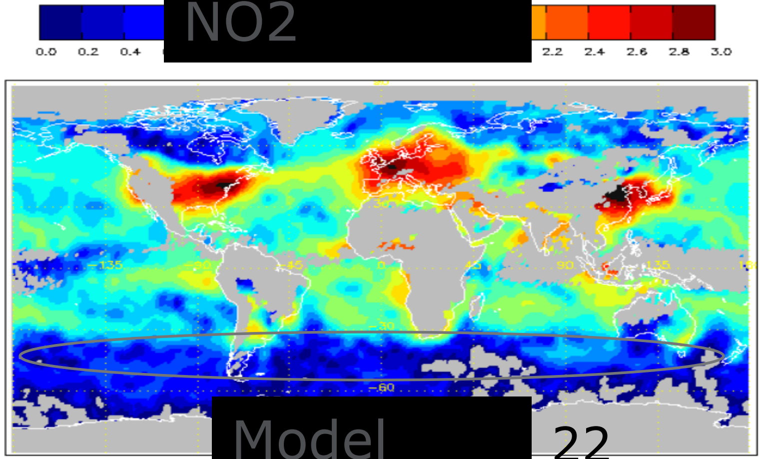
European Space Agency

Backup slides

The geographical distribution of model vs observed NO2 below 820 hPa (land source are urban emissions in US, Europe and China) suggest that horizontal diffusion by model winds (ERA Interim) is not vigorous enough…



Observed NO2



Model NO2

[Belmonte et al, OMI tropospheric NO2 profiles, ACP, 2015]

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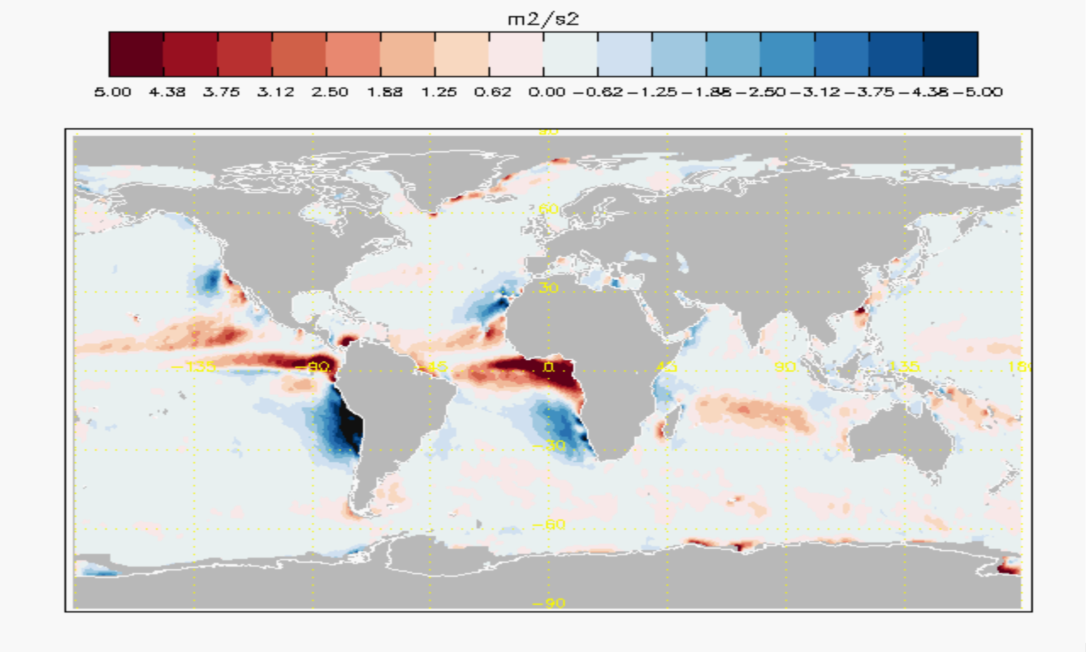
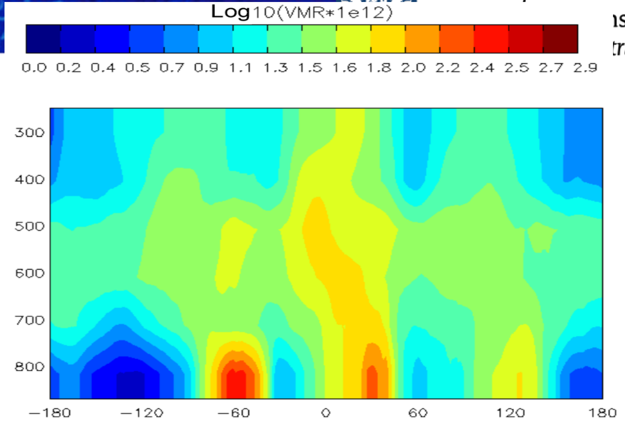
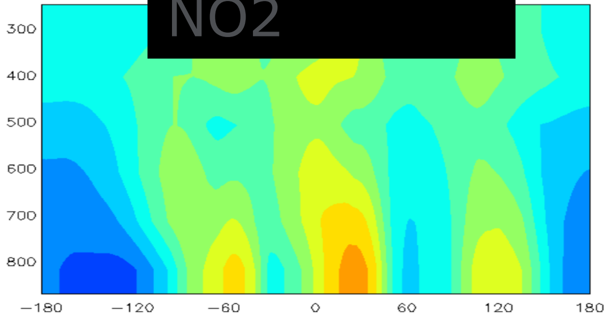
Departures in meridional mean kinetic energy

ASCAT minus ERA interim
2012





Observed NO2



Model NO2

European Space Agency

Effect of ocean currents

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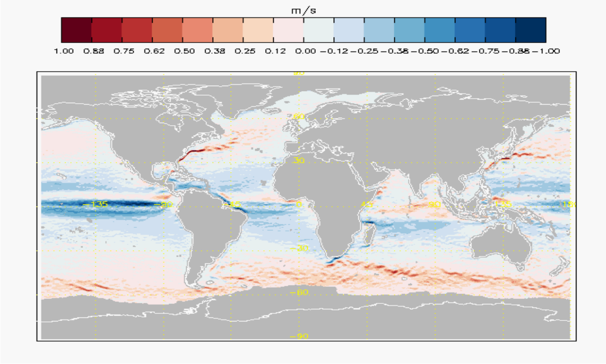
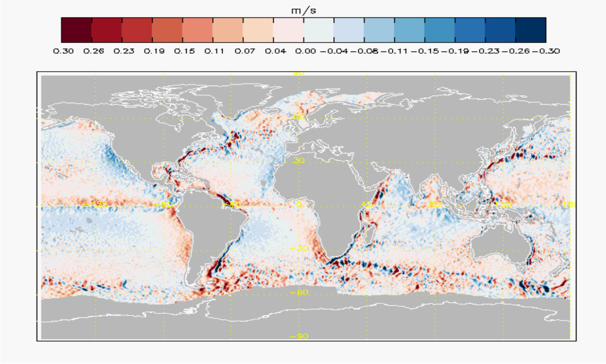
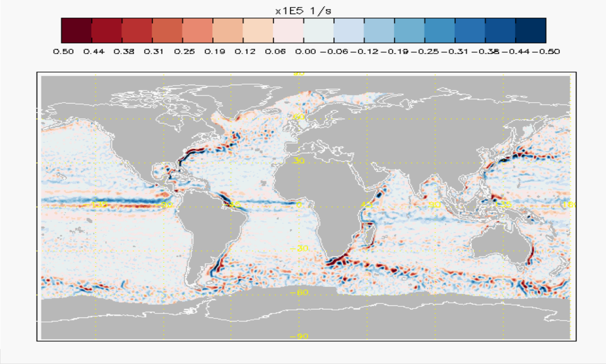
Copernicus Globcurrent



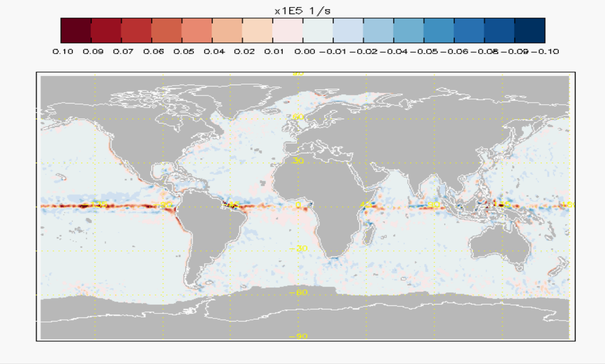
Mean zonal



Mean meridional



Vorticity

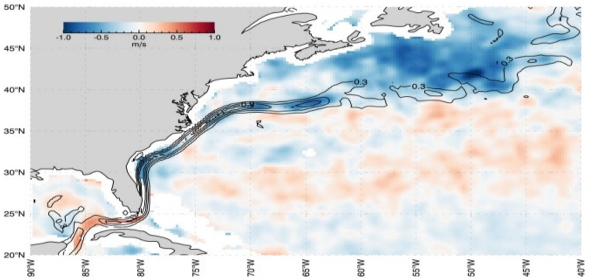


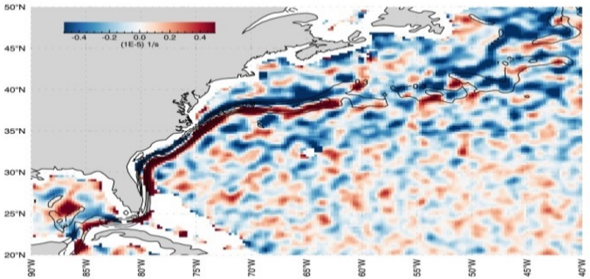
Divergence

Effect of Globcurrent

Gulf Stream

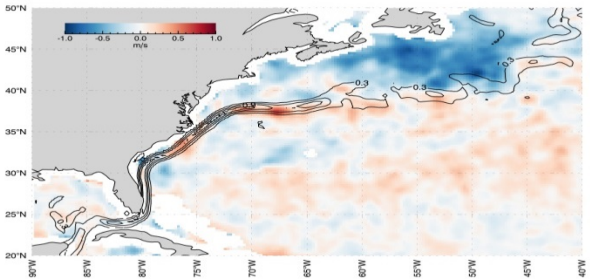
Before

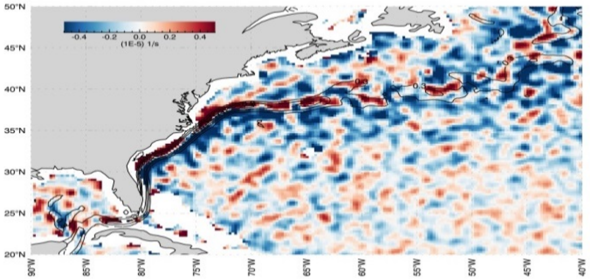




Contours are ocean velocities

After the correction





Mean wind speed differences to ERA5

Mean stress curl differences to ERA5