Near-surface wind and wave drift currents in the coupled air-sea boundary layer

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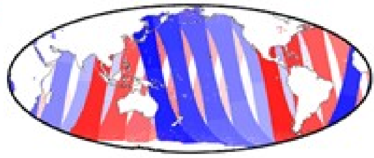
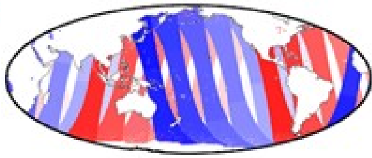


Initial project goals:

- Compute and analyze global statistics of near-surface wind and wave drift from recently proposed equilibrium-sea model (Samelson 2022, JPO) and MERRA-2 reanalysis winds.
- Motivation: Contribute to risk reduction for ODYSEA satellite Doppler scatterometer by improving quantitative characterization and physical understanding of near-surface currents driven by wind and waves.
- Model:
  - Ekman-like balance of Coriolis force and vertical divergence of effective stress
  - Mass-weighted, surface-conforming mean velocity includes wave (Stokes) drift
  - Effective stress divergence uses mixing length with parameterized roughness length and wave-correction factor

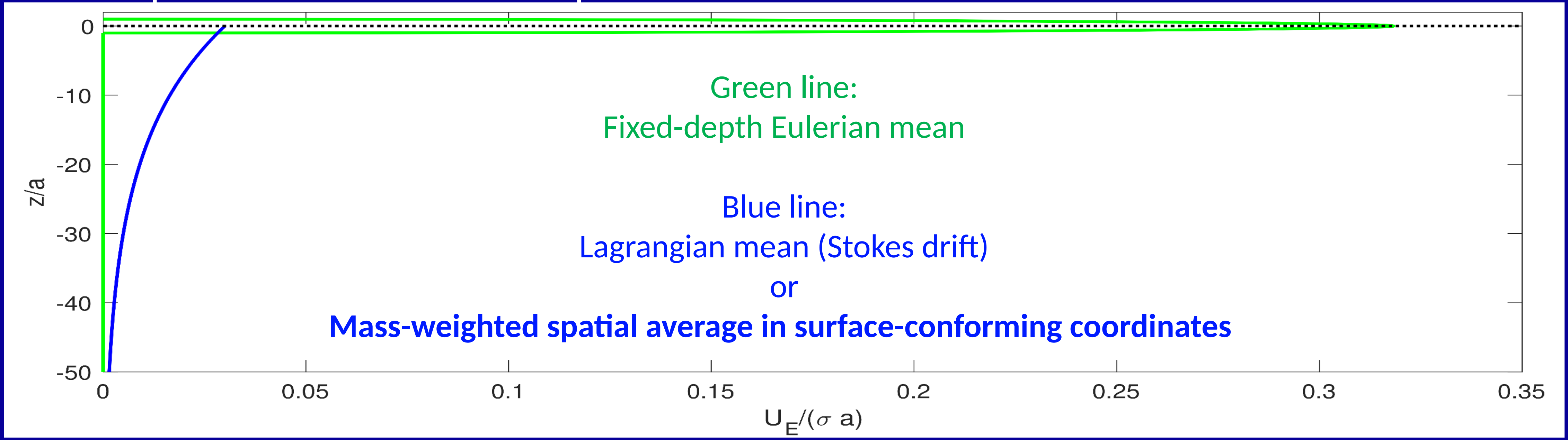


Wind drift model: What about waves and wave (Stokes) drift?

- Wave momentum (Stokes drift) of equilibrium-sea wave field is part of wind ("Ekman") drift.
- Wave momentum is captured in full-depth Eulerian means:

  Fixed-depth Eulerian mean places wave momentum above wave troughs.

  Mass-weighted surface-conforming mean gives Eulerian mean profile equivalent to Stokes drift profile.



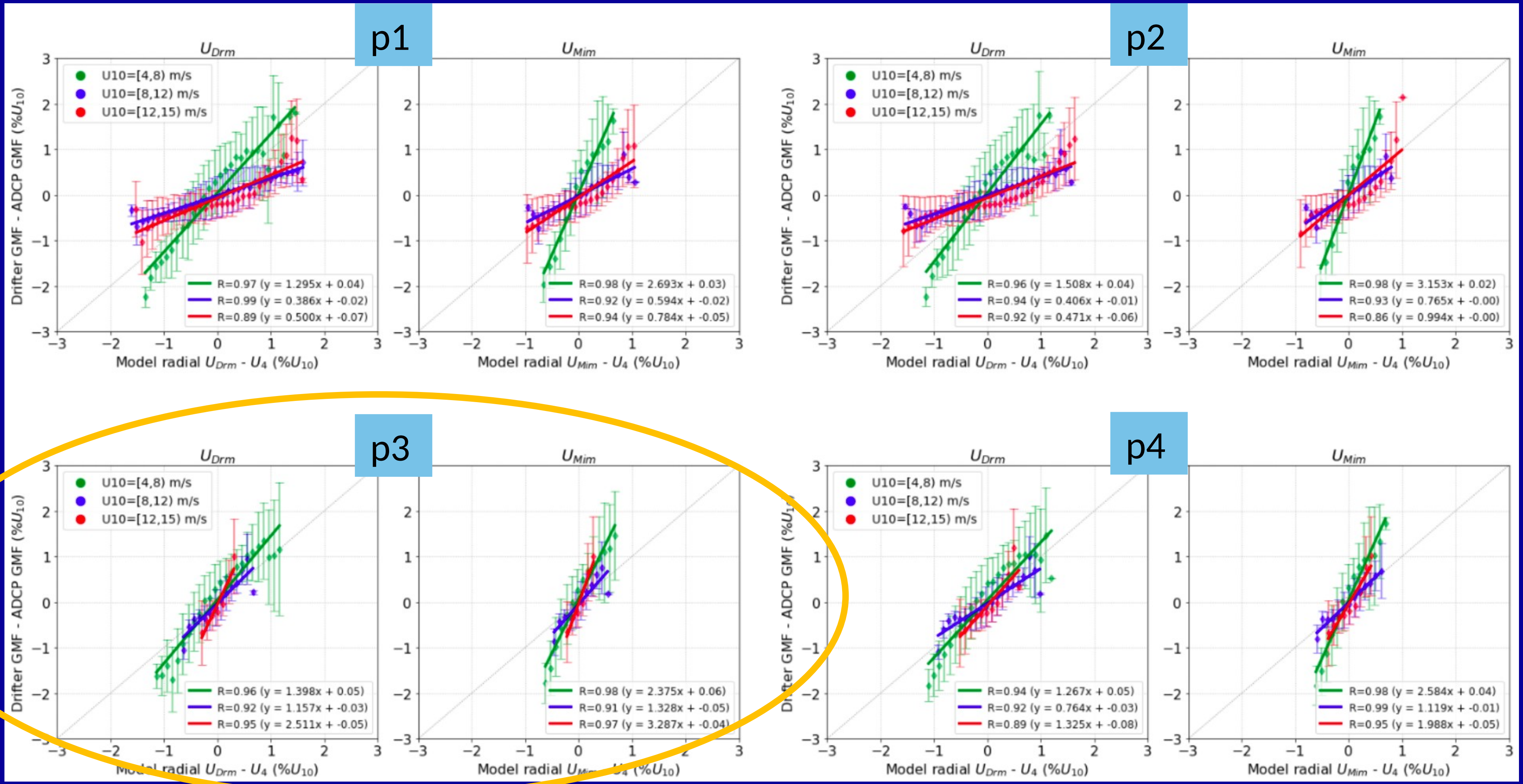
Drift model: $z_{0o}(U_{10N})$ and $\phi_w(U_{10N})$ parameterizations

Samelson (2022): "p1" and "p2"

Leyba et al. (in preparation; comparison with S-MODE data): "p3" and "p4"

Colors: 10-m wind-speed intervals*

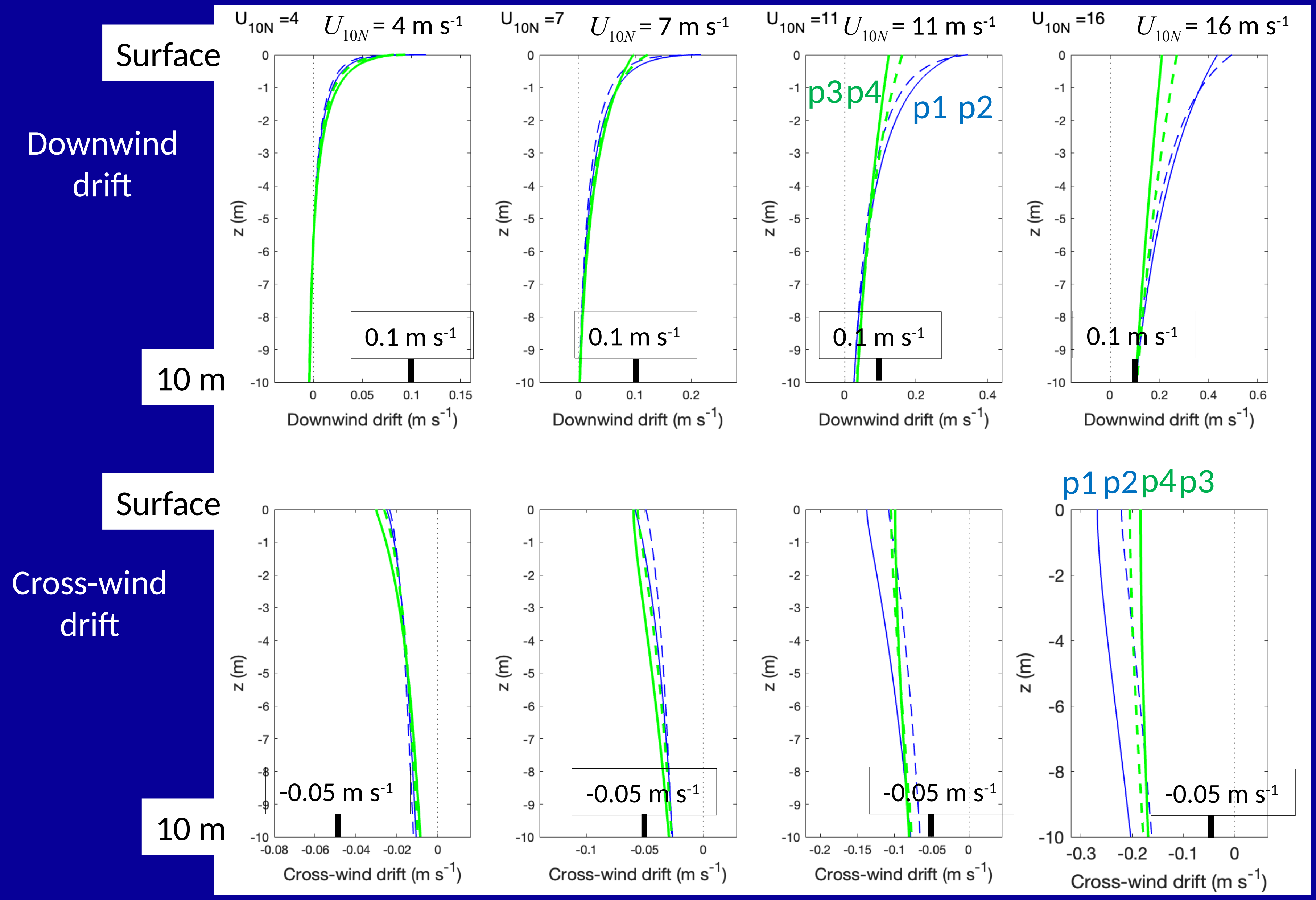
DopplerScatt GMF wind-drift estimates (% U_{10N})



Drift model predictions (% U_{10N})

*Estimates of shear between drifter and 4-m ADCP depths; not monotonic with U_{10N}

Model wind drift vs. 10-m wind speed at 37.5° N

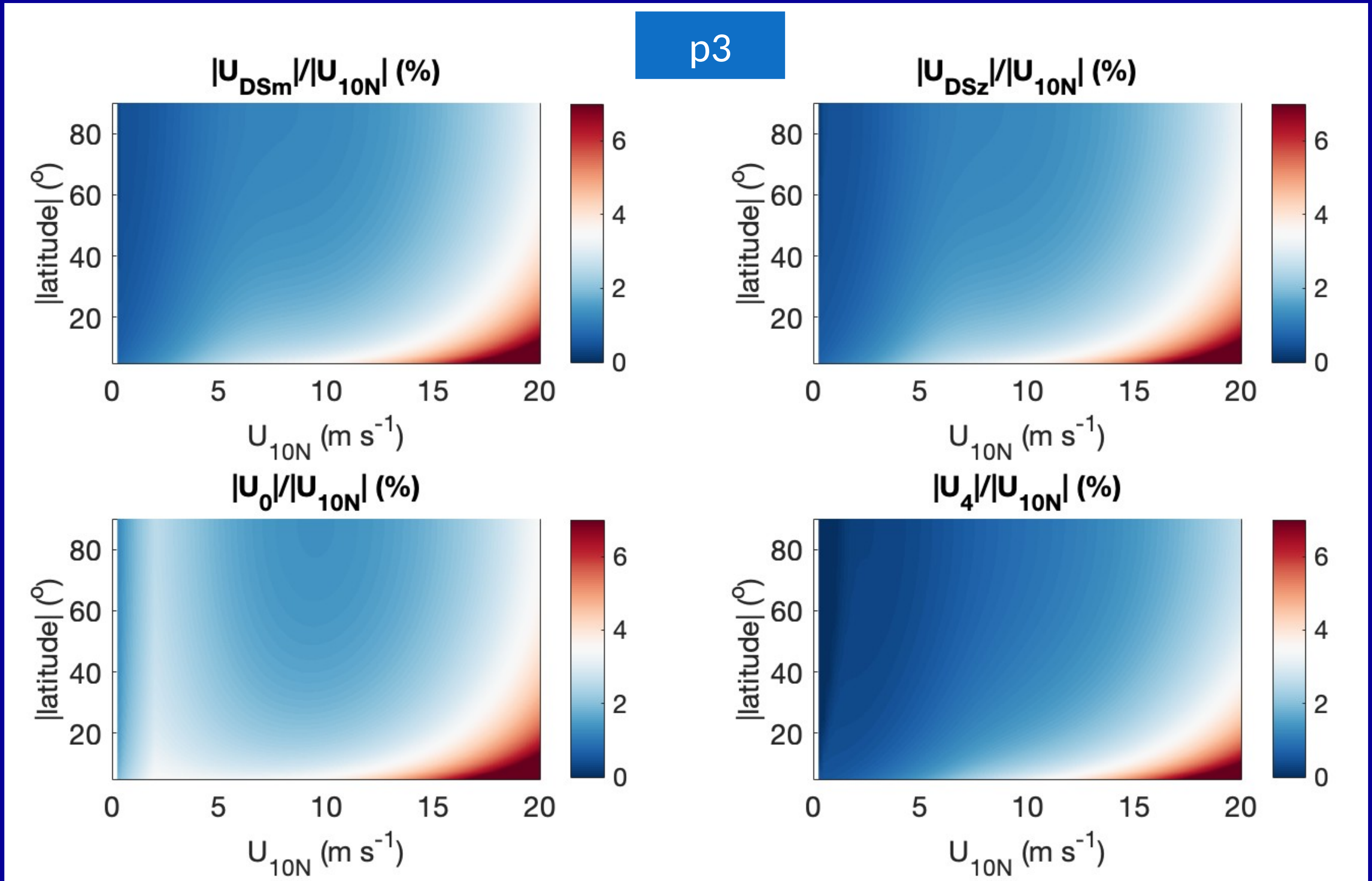


For $U_{10N} > 5$ m s-1, p3 and p4 have less near-surface downwind shear and drift than p1 and p2.

Model wind drift speed ($\% \; U_{10N}$) vs. 10-m wind speed and latitude

”DopplerScatt mean”
0-1.6 m depth

”DopplerScatt mid-point”
0.8 m depth



Surface (z=0)

4-m depth
[nominal DopplerScatt ADCP calibration depth]

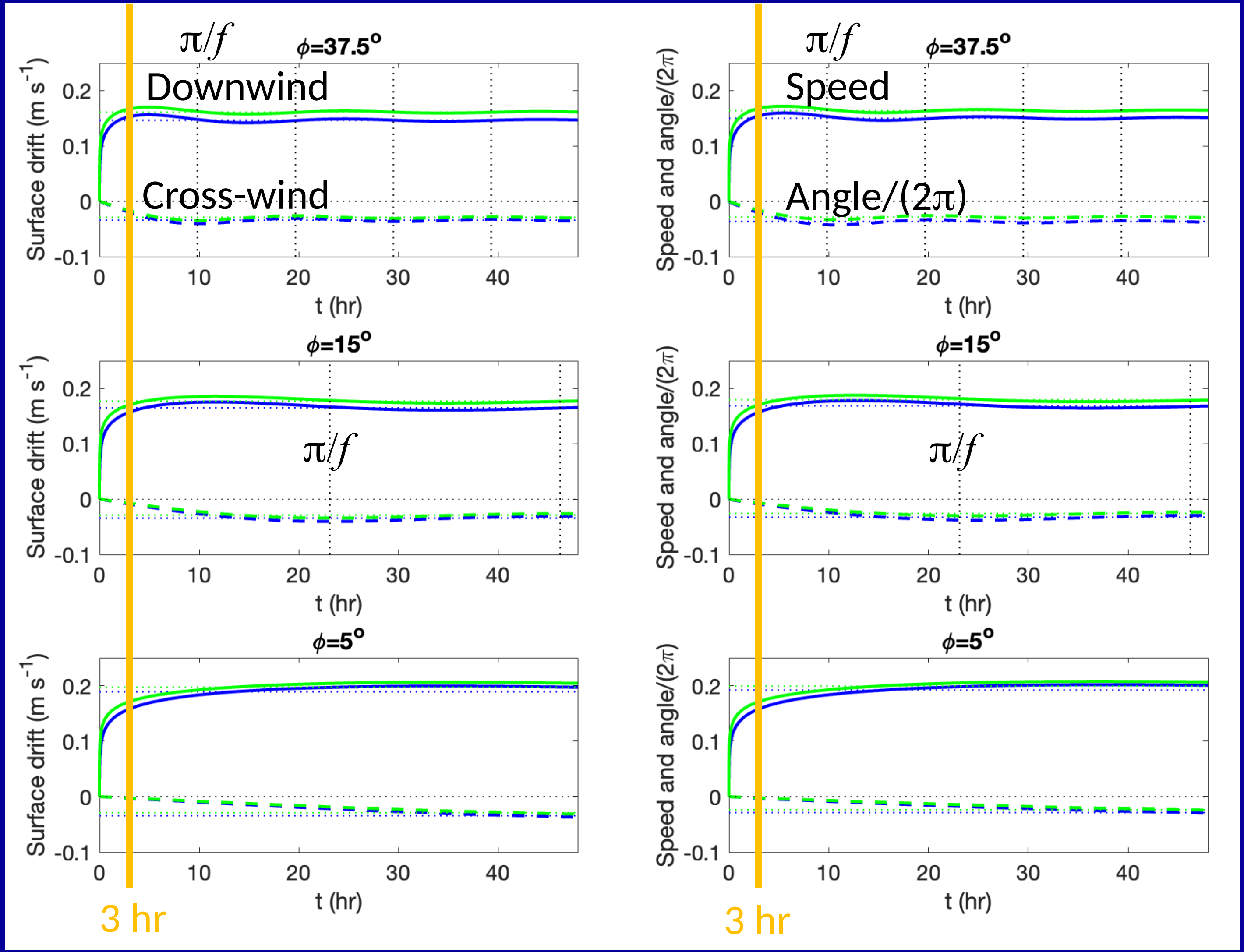
Equilibration time for surface wind drift

Estimated for $U_{10N} = 5\ \mathrm{m\ s^{-1}}$ using Madsen (1977) law-of-the-wall log-Ekman solution

37.5° N

15° N

5° N



Downwind velocity: O(3 hr)

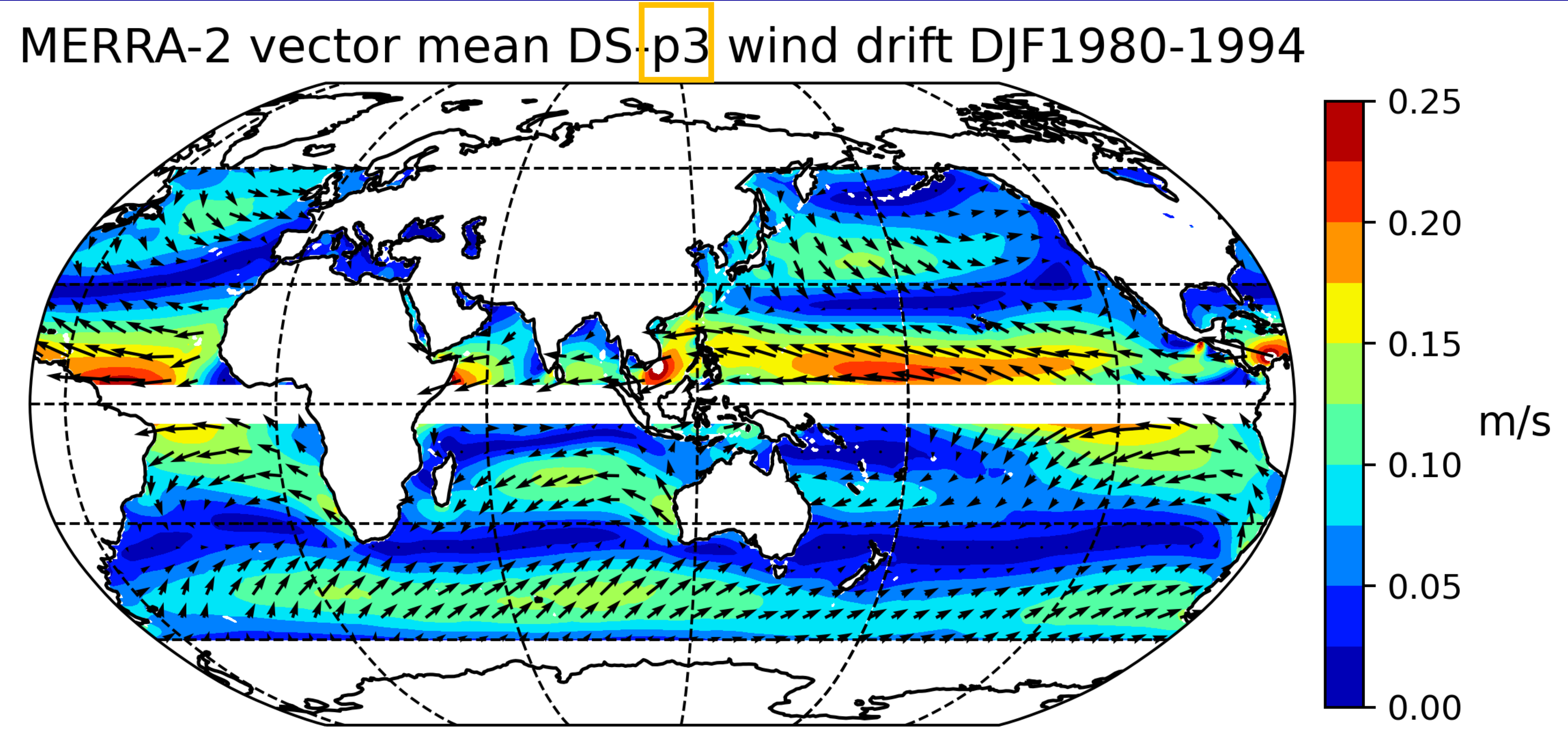
Cross-wind velocity: O(1/f)

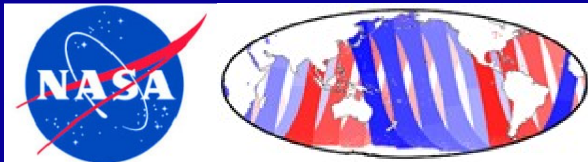
NB: Downwind equilibration time similar to wind-sea equilibration time

=> Consider drift velocities forced by 3-hr-mean and 24-hr-mean reanalysis winds

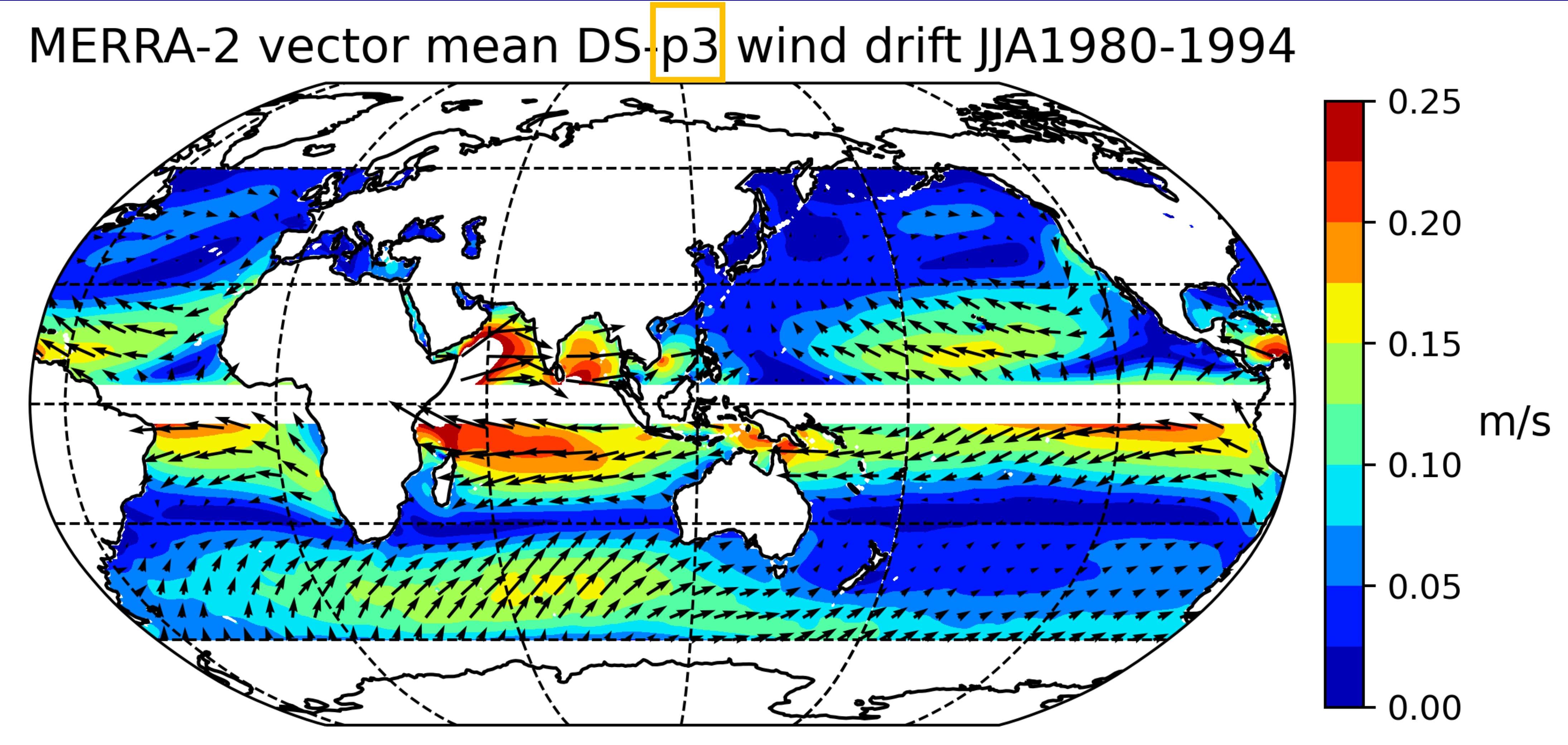
Remote-sensing observations: Instantaneous wind-drift effectively gives time-integrated wind history

“DopplerScatt mean” 1980-1994 DJF wind drift from 3-hr vector-mean wind

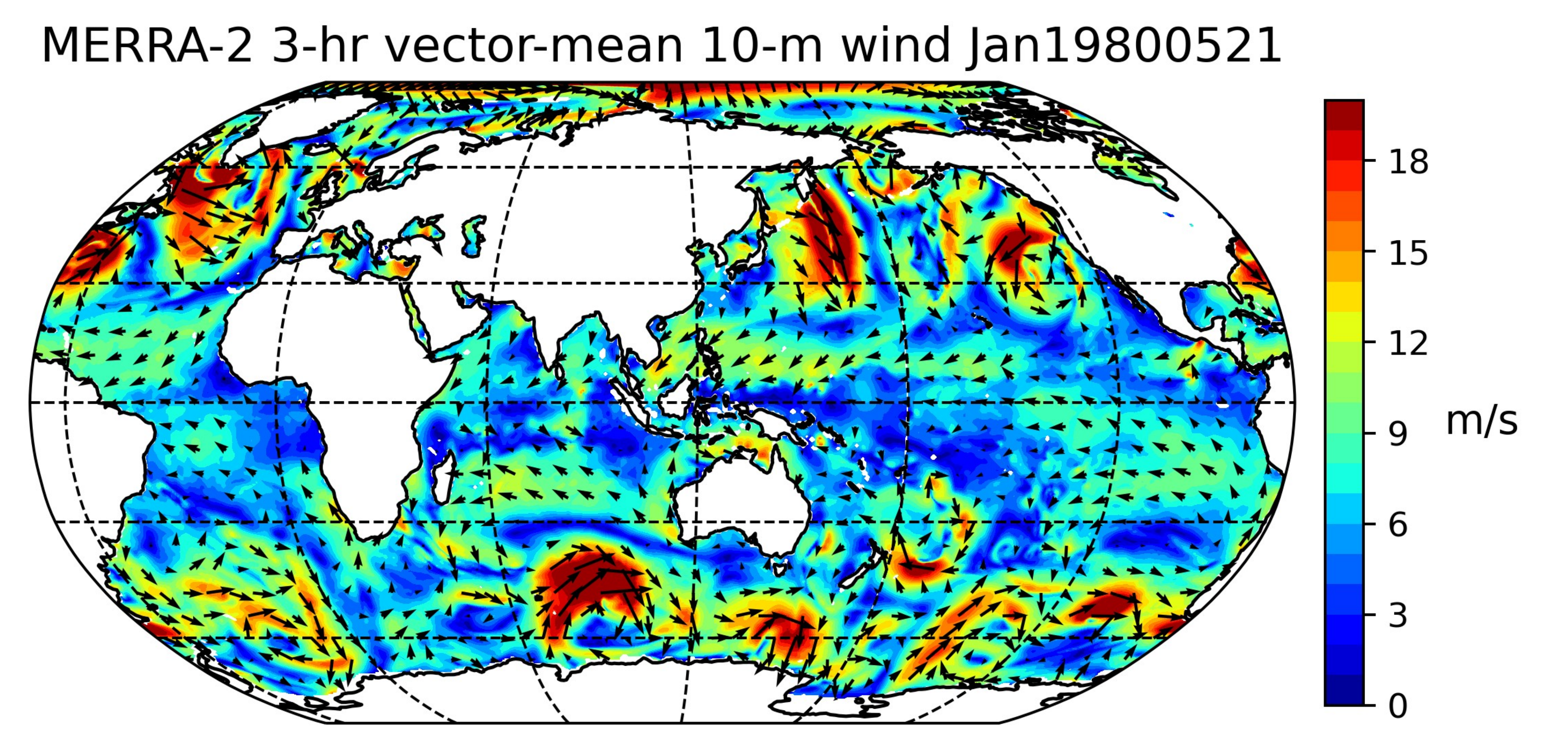




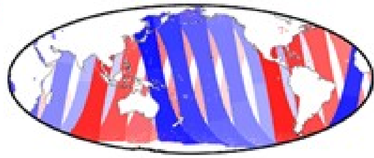
“DopplerScatt mean” 1980-1994 JJA wind drift from 3-hr vector-mean wind



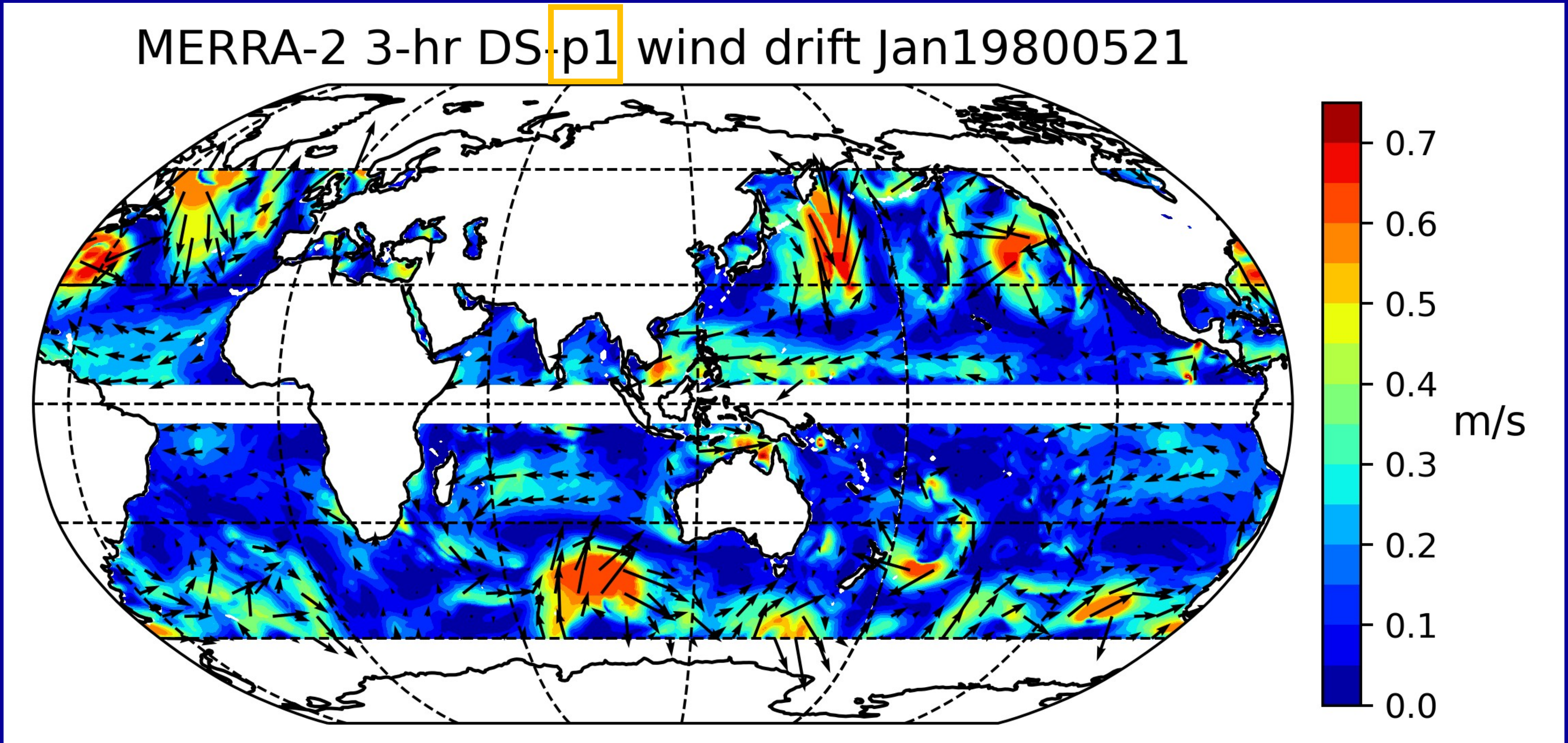
MERRA-2 winds: 2230 UTC 05 Jan 1980 3-hr vector-mean of hourly fields



MERRA-2 reanalysis: GEOS-5 model, 50km×50km model grid, 0.625°×0.5° output-field grid



“DopplerScatt mean” wind drift from 2230 UTC 05 Jan 1980 3-hr mean



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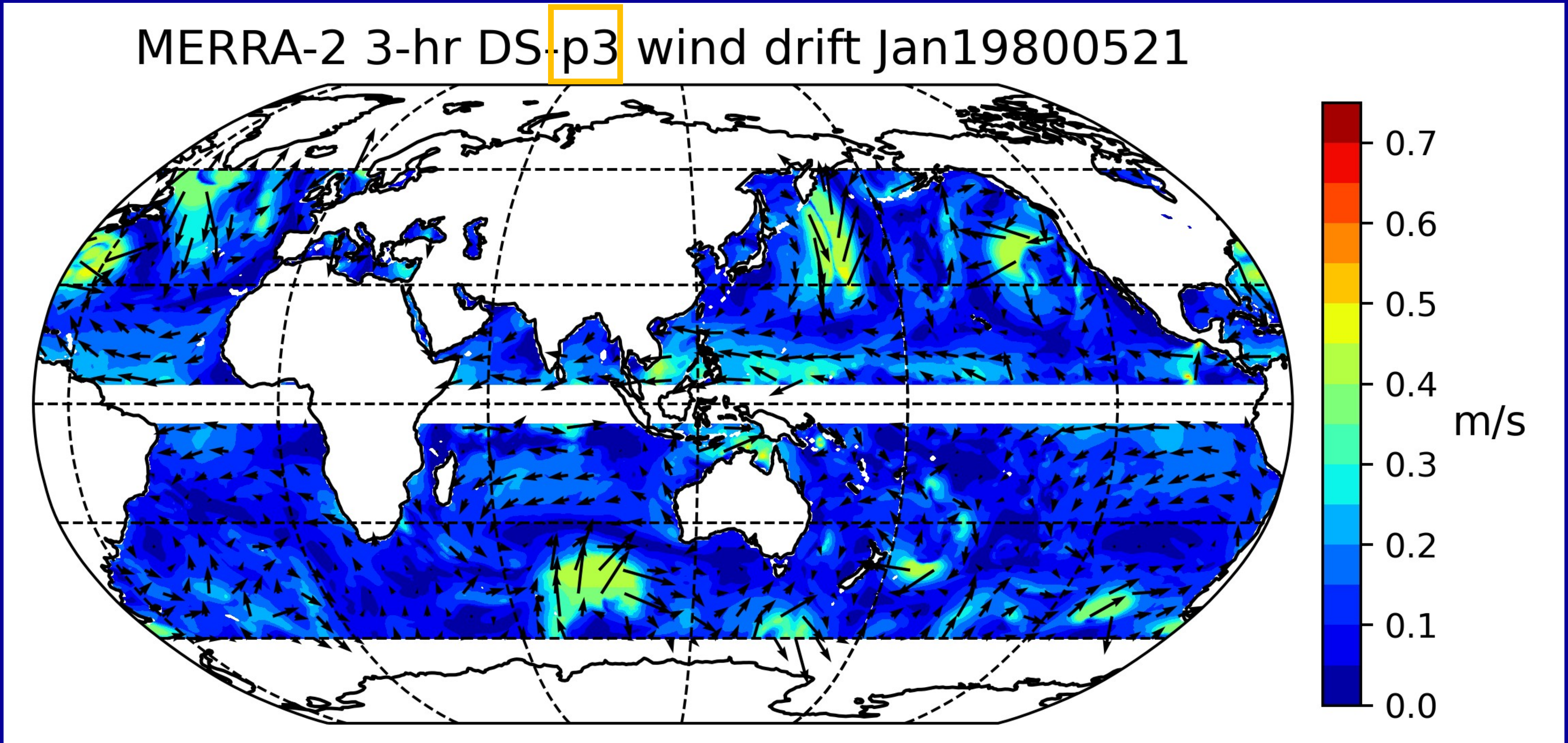
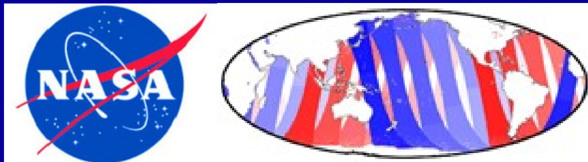
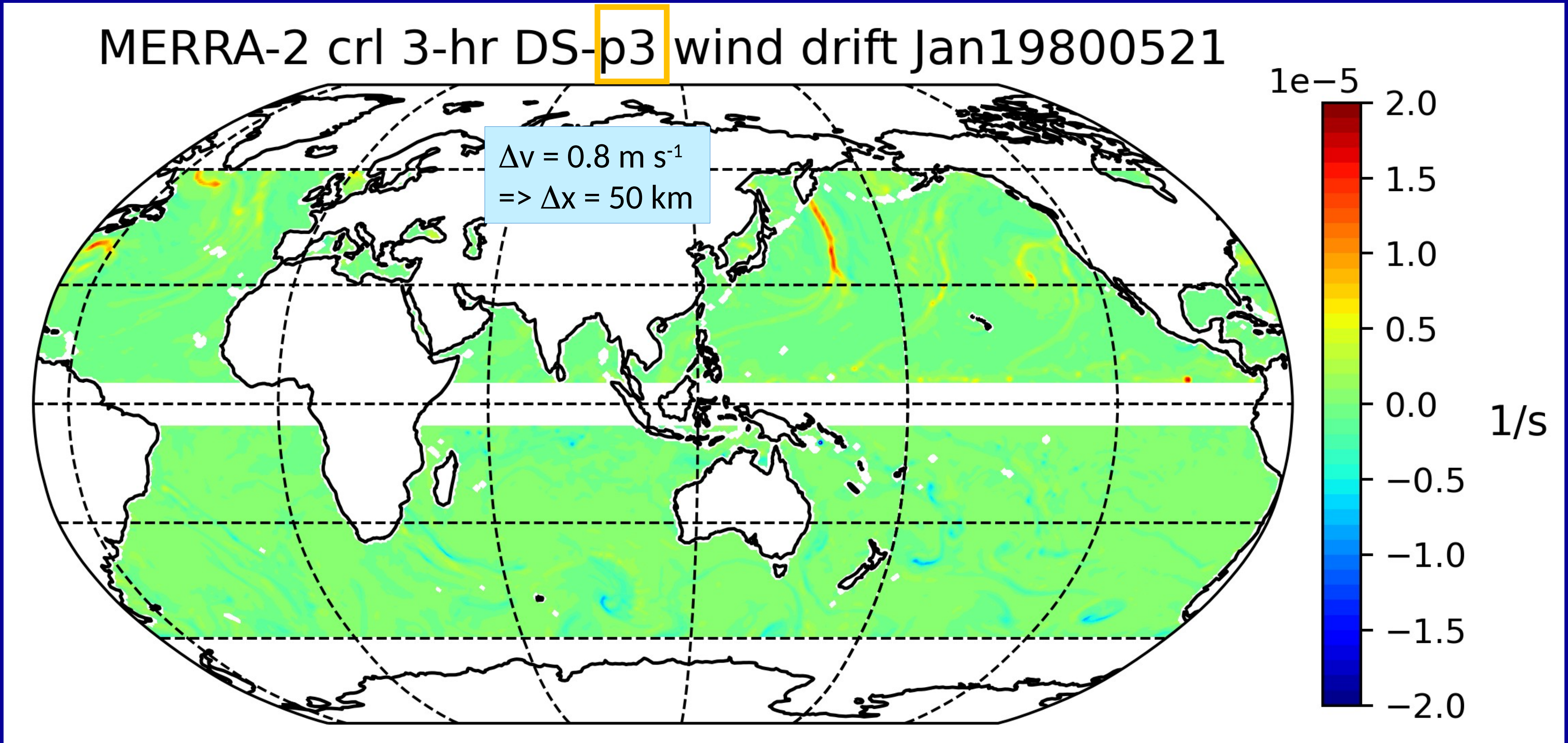




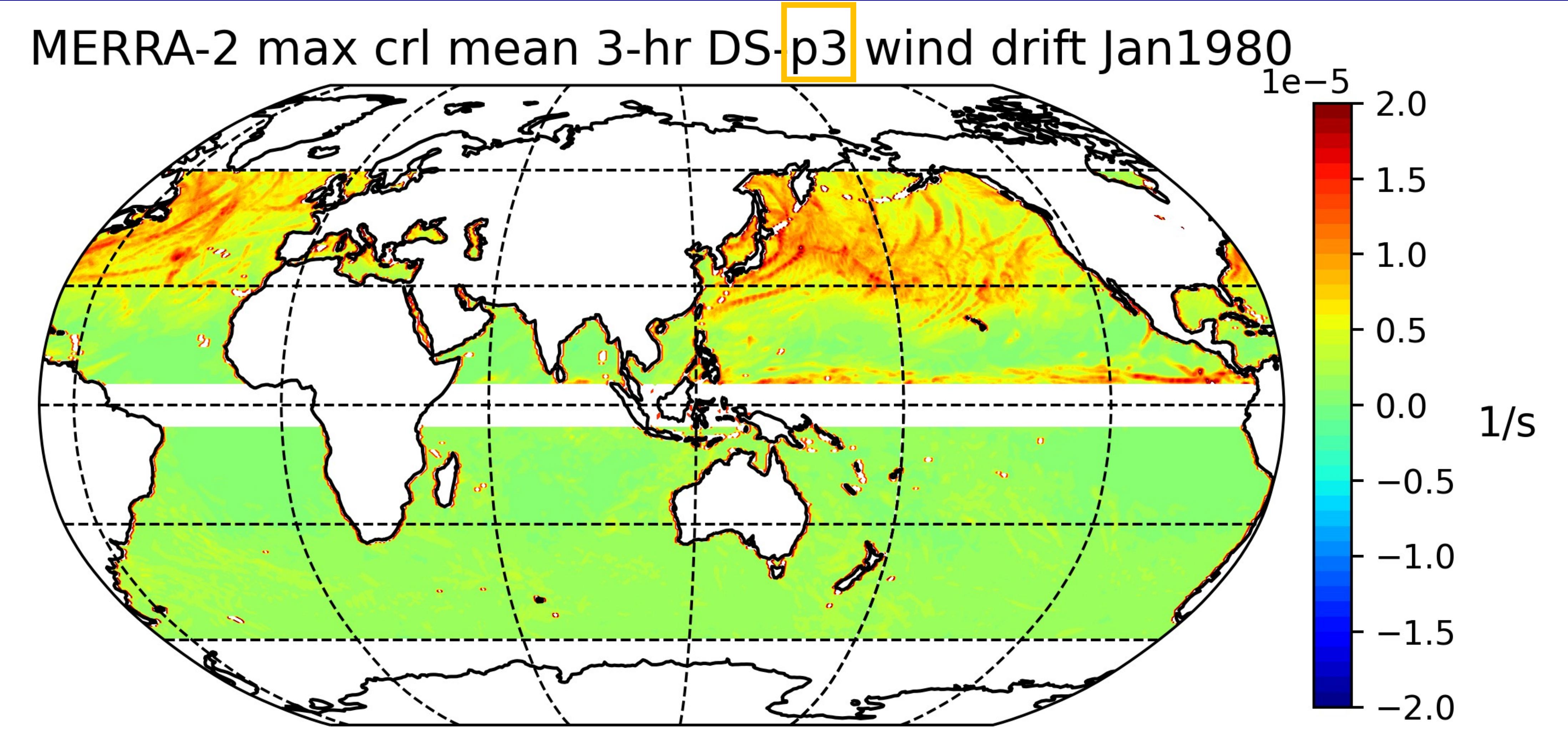
Curl of “DopplerScatt mean” wind drift from 2230 UTC 05 Jan 1980 3-hr mean



$\Delta v = 0.8\ m\ s^{-1}$
=> $\Delta x = 50$ km

MERRA-2 reanalysis: GEOS-5 model, 50km×50km model grid, 0.625°×0.5° output-field grid

Curl of “DopplerScatt mean” wind drift from 3-hr vector-mean wind: max{Jan 1980}



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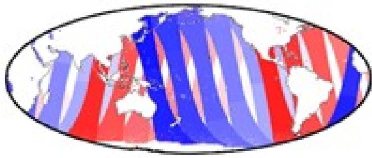
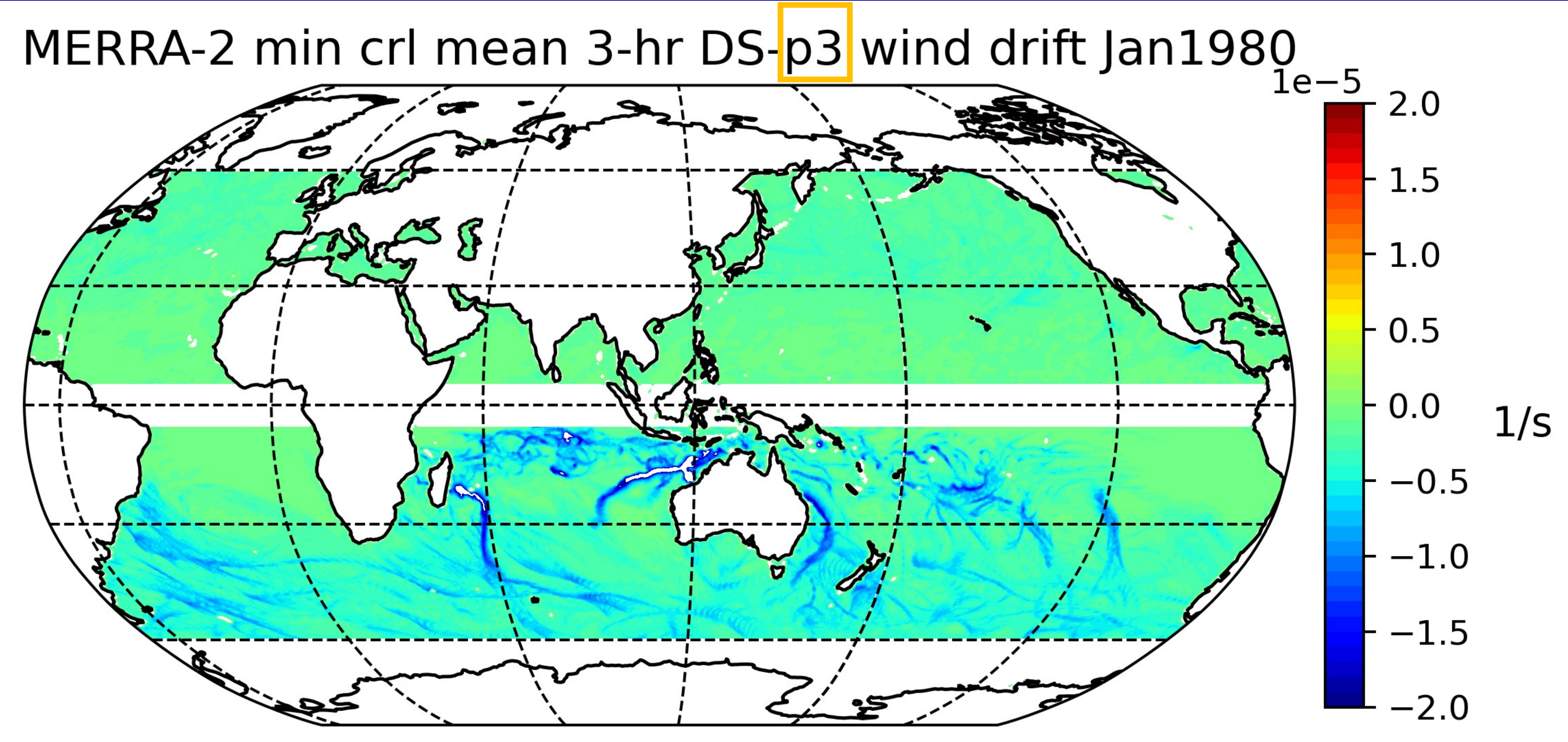
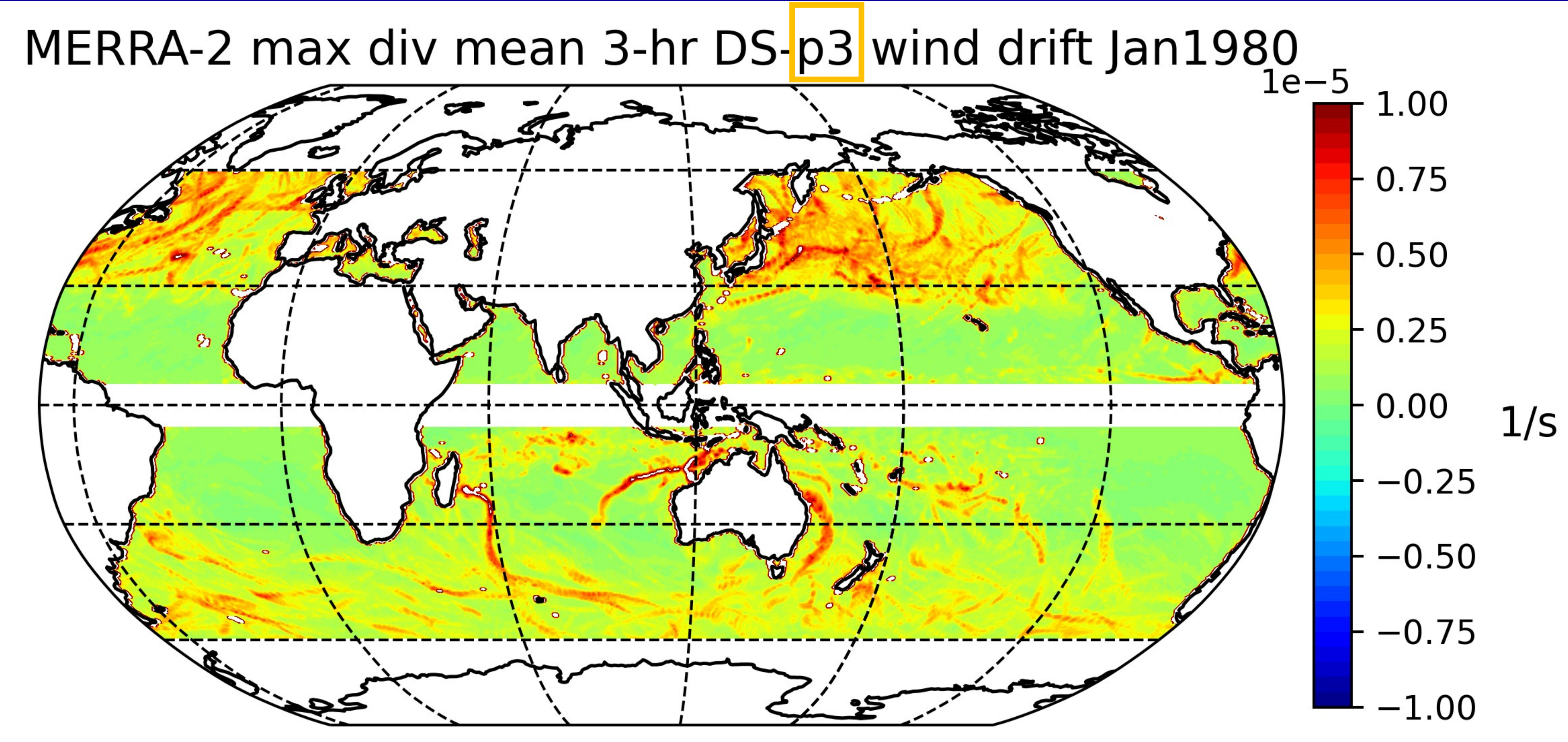


Curl of “DopplerScatt mean” wind drift from 3-hr vector-mean wind: min{Jan 1980}

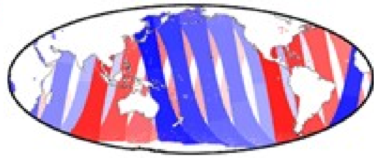


MERRA-2 reanalysis: GEOS-5 model, 50km×50km model grid, 0.625°×0.5° output-field grid

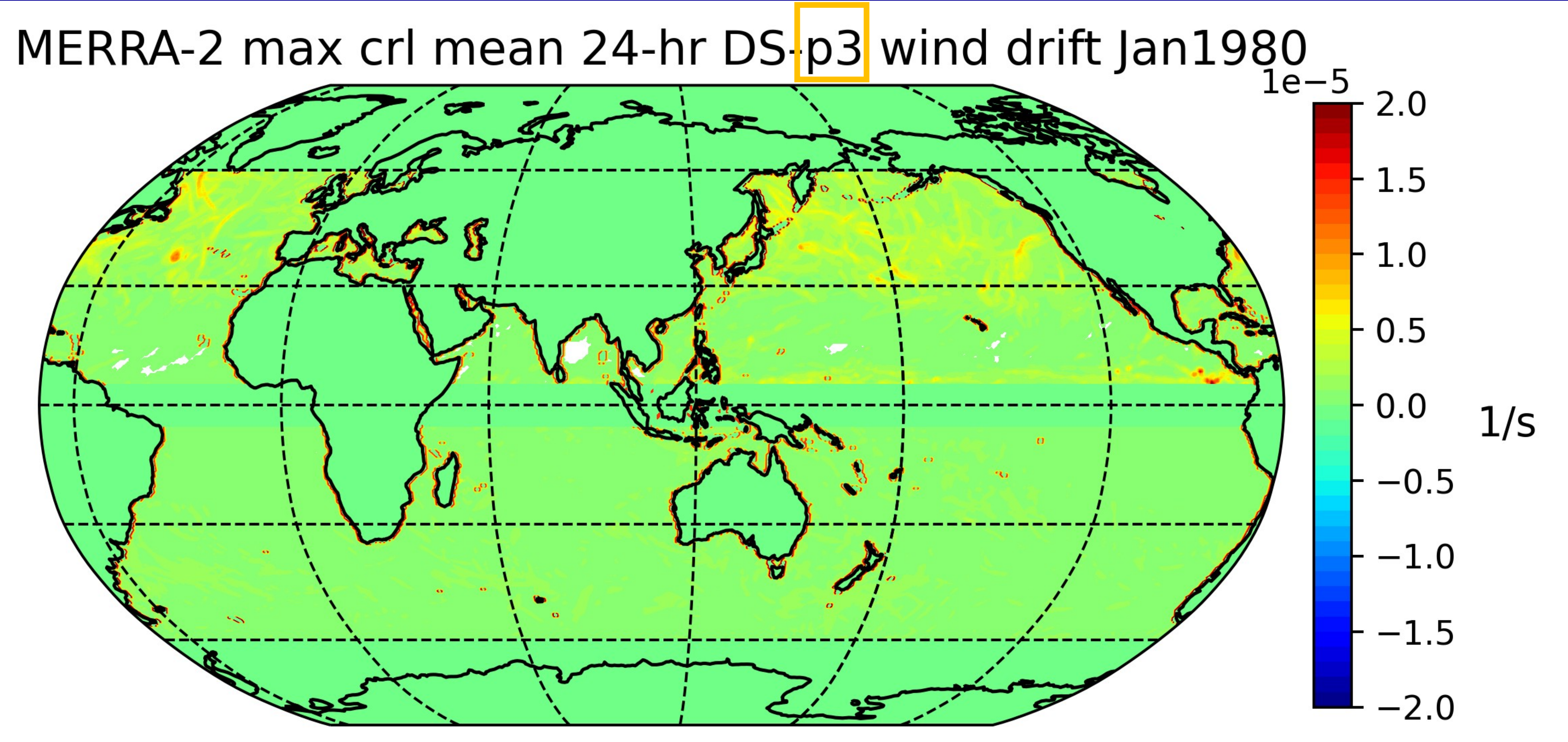
Div of “DopplerScatt mean” wind drift from 3-hr vector-mean wind: max{Jan 1980}



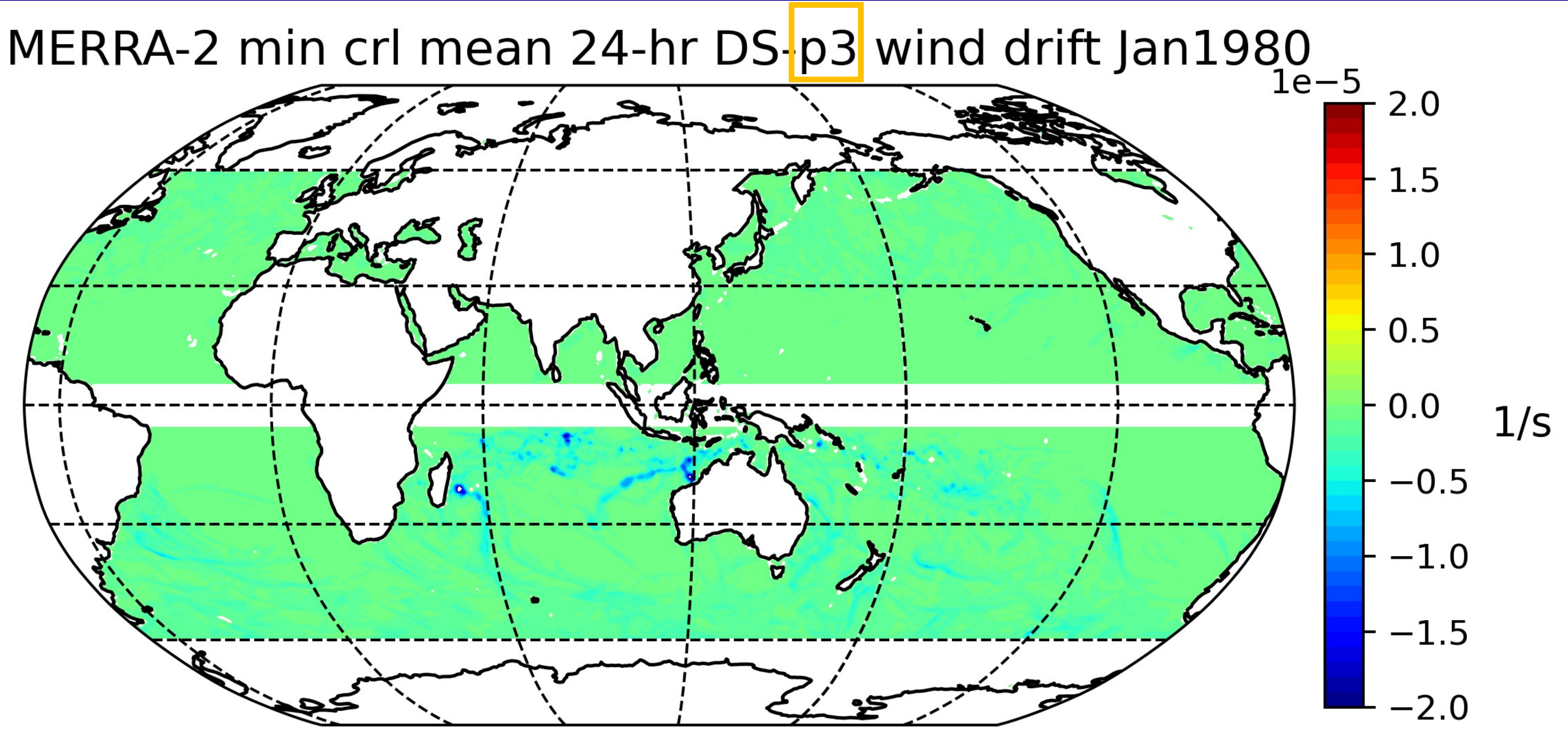
MERRA-2 reanalysis: GEOS-5 model, 50km×50km model grid, 0.625°×0.5° output-field grid



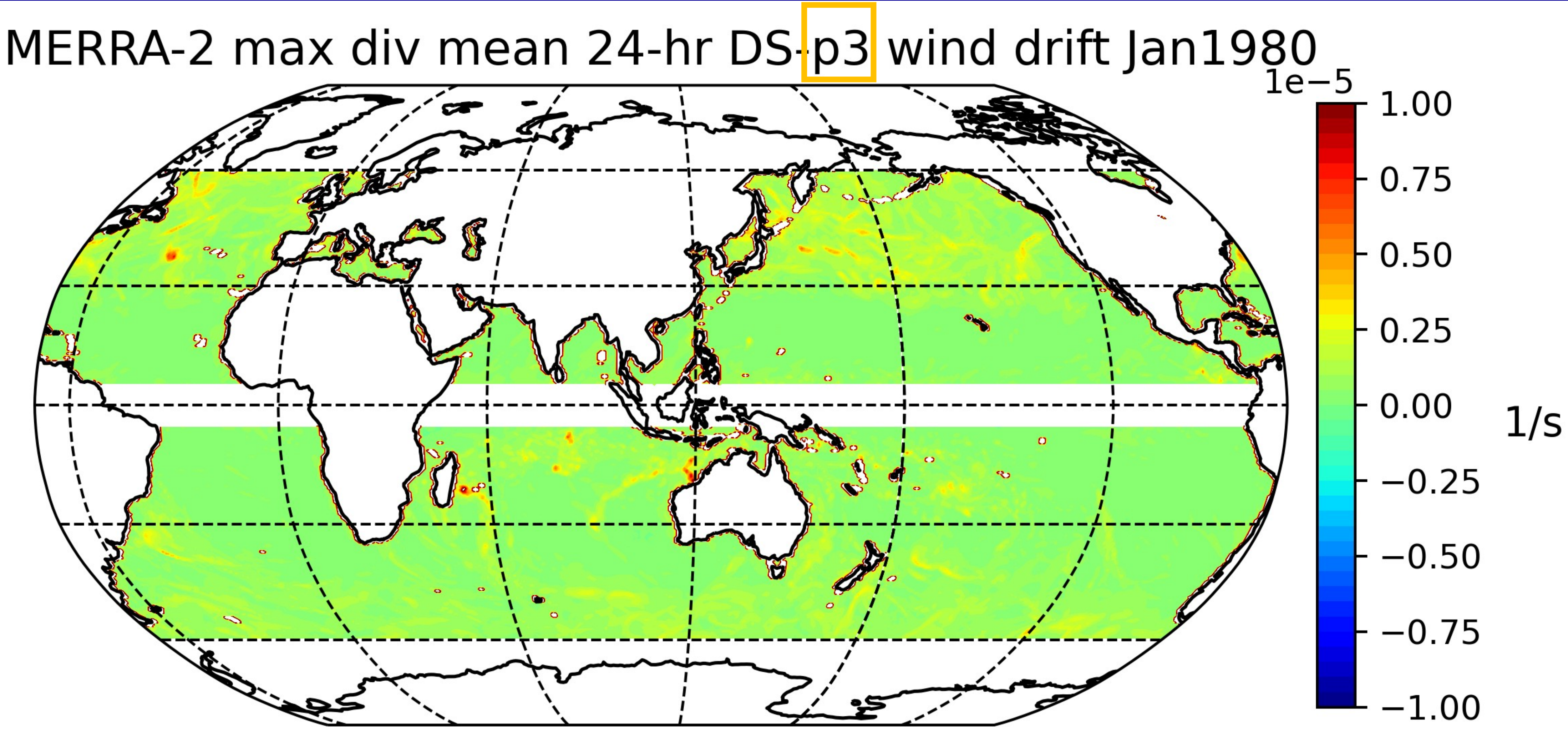
Curl of “DopplerScatt mean” wind drift from 24-hr vector-mean wind: max{Jan 1980}



Curl of “DopplerScatt mean” wind drift from 24-hr vector-mean wind: min{Jan 1980}



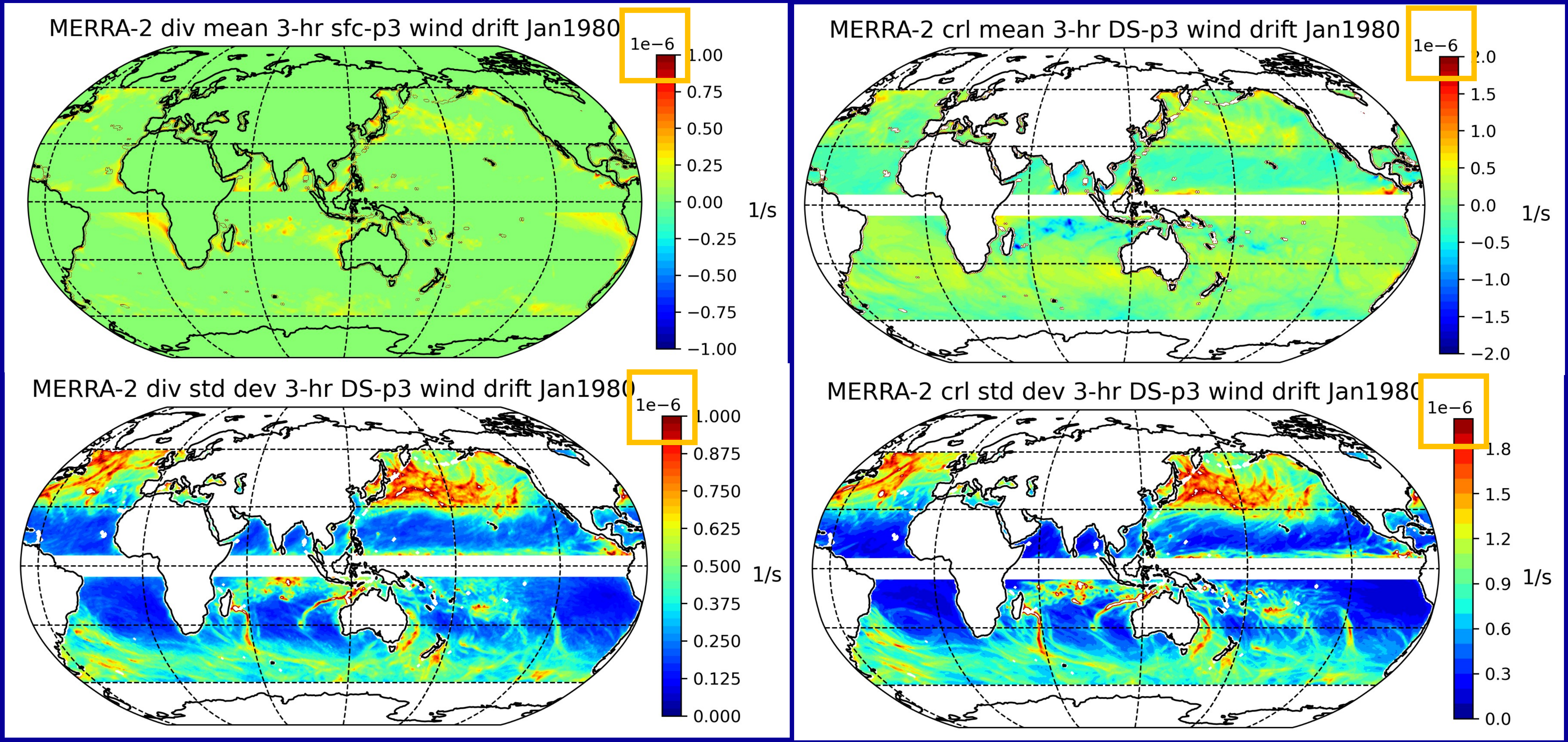
Div of “DopplerScatt mean” wind drift from 24-hr vector-mean wind: max{Jan 1980}



Mean & std dev of div & curl of 3-hr p3 “DopplerScatt mean” wind drift: Jan 1980

mean

std dev



divergence

curl

What fraction of wind drift is carried as Stokes drift (wave momentum)?

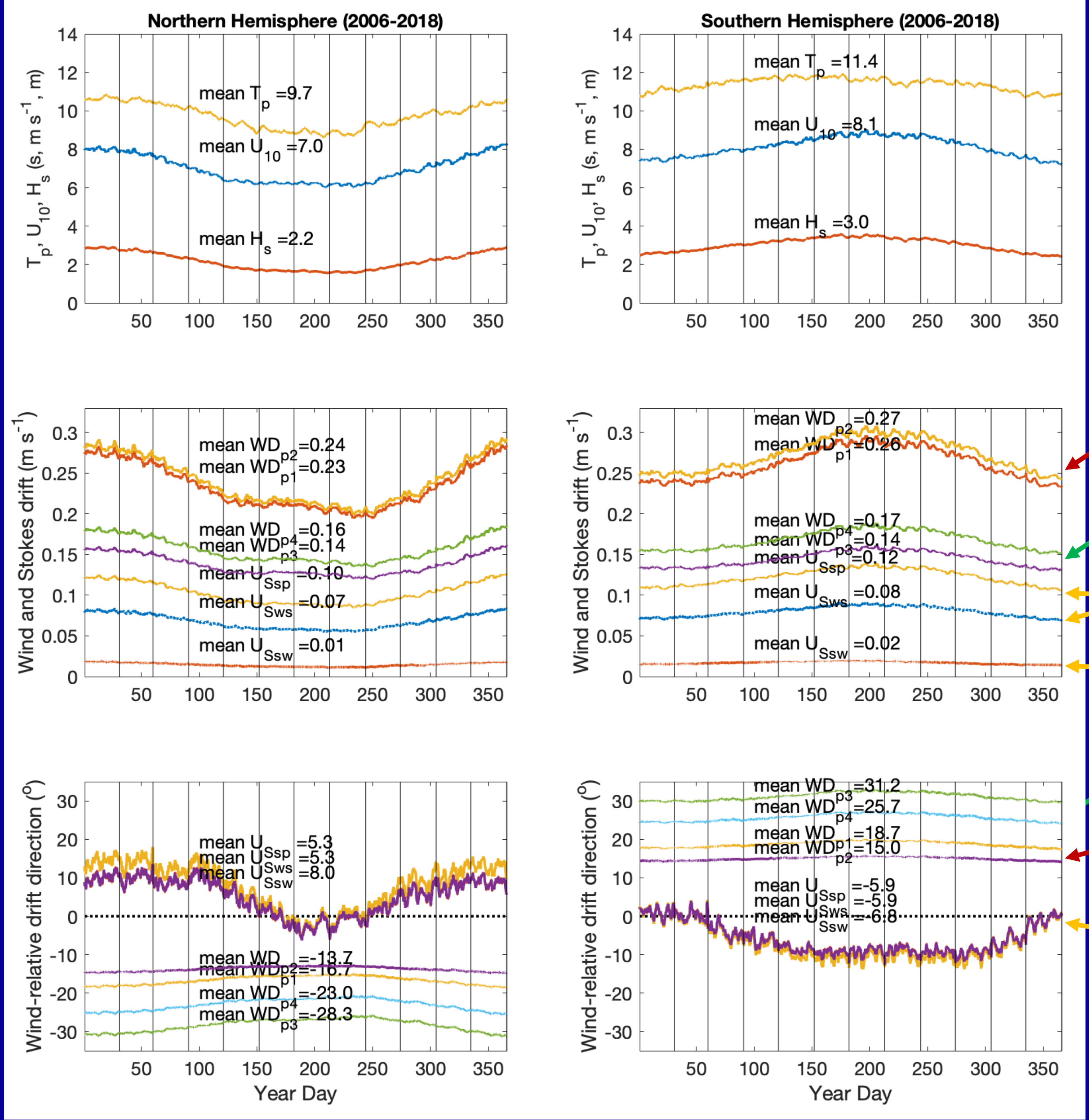
Seasonal cycles from 2006-2018 WaveWatch III hindcast

Mean 3-hr wave parameters (T_p, U_{10}, H_s)

Mean surface drift speed

Wave-age parameter used to distinguish wind-sea from swell

Mean surface wind-relative drift angle



Mean	NH	SH	
U_{10}	7	8.1	m s^{-1}
H_s	2.2	3.0	m
T_p	9.7	11.4	s

p1, p2 wind drift (45%)

p3, p4 wind drift (85%)

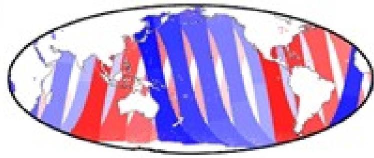
wind-sea Stokes drift

swell Stokes drift

p3, p4 wind drift

p1, p2 wind drift

Stokes drift



Summary

- Global statistics of near-surface wind and wave drift from recently proposed equilibrium-sea model have been computed from MERRA-2 reanalysis winds. Motivation includes ODYSEA risk reduction.
- Remote-sensing observations: Instantaneous wind-drift effectively gives time-integrated wind history.
- Modified parameterizations suggested by S-MODE calibration data have less near-surface downwind drift and shear than original parameterizations.
- Seasonal mean 3-hr “DopplerScatt-depth” drift velocities reach 0.15-0.25 m s^{-1}.
- Monthly maximum abs(divergence) and abs(curl) of 3-hr “DS” drift velocities reach 1-2 x 10^{-5} s^{-1} across midlatitudes and in some tropical regions.
- Maximum abs(curl) are for positive curl in NH and negative curl in SH while maximum abs(divergence) are for positive divergence in both hemispheres.
- Magnitudes of monthly mean and std dev divergence and curl of 3-hr “DS” drift velocities reach 0.5-2 x 10^{-6} s^{-1} in midlatitudes and some tropical regions.
- Much of wind drift may be carried as wave (Stokes) drift…?