and pleasant daydreams (*19–21*). Research has shown that minds are difficult to control (*8*, *22*), however, and it may be particularly hard to steer our thoughts in pleasant directions and keep them there. This may be why many people seek to gain better control of their thoughts with meditation and other techniques, with clear benefits (*23–27*). Without such training, people prefer doing to thinking, even if what they are doing is so unpleasant that they would normally pay to avoid it. The untutored mind does not like to be alone with itself.

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SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/345/6192/75/suppl/DC1
Materials and Methods
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Fig. S1
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CLIMATE CHANGE

Climate change and wind intensification in coastal upwelling ecosystems

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In 1990, Andrew Bakun proposed that increasing greenhouse gas concentrations would force intensification of upwelling-favorable winds in eastern boundary current systems that contribute substantial services to society. Because there is considerable disagreement about whether contemporary wind trends support Bakun's hypothesis, we performed a meta-analysis of the literature on upwelling-favorable wind intensification. The preponderance of published analyses suggests that winds have intensified in the California, Benguela, and Humboldt upwelling systems and weakened in the Iberian system over time scales ranging up to 60 years; wind change is equivocal in the Canary system. Stronger intensification signals are observed at higher latitudes, consistent with the warming pattern associated with climate change. Overall, reported changes in coastal winds, although subtle and spatially variable, support Bakun's hypothesis of upwelling intensification in eastern boundary current systems.

In eastern boundary current systems (EBCSs), coastal upwelling fuels high productivity, supporting vast and diverse marine populations. With a surface area of only ~2% of the global oceans, EBCSs provide upward of 20% of wild marine-capture fisheries (*1*) as well as essential habitat for marine biodiversity (*2*). Understanding upwelling variability is also key to assessments of marine ecosystem health, influencing factors such as ocean acidification and deoxygenation (*3–5*). Although the ecological relevance of upwelling is clear, the future of upwelling under anthropogenic climate change is not (*6–8*). In 1990, Andrew Bakun hypothesized that global warming could result in steeper temperature and sea-level pressure gradients between the oceans and the continents, causing alongshore upwelling-favorable winds to intensify (*6*). Although the increase in global temperatures is unquestioned (*7*), its influence on upwelling-favorable winds remains uncertain. In an attempt to resolve disagreement in the literature concerning the intensification of upwelling winds, we conducted a "preponderance of evidence" meta-analysis on results from previous studies that tested Bakun's wind intensification hypothesis. Our meta-analysis focused on the outcome of Bakun's purported mechanism: upwelling-favorable wind intensification over the past 6+ decades.

We synthesized results from 22 studies published between 1990 and 2012, 18 of which contained quantitative information on wind trends. Our resulting database contains 187 non-independent wind trend analyses based on time series ranging in duration from 17 to 61 years [tables S1 to S3 (*9*)]. We tested whether the evidence from these studies was consistent (increasing winds) or inconsistent (weakening winds) with the Bakun hypothesis. Bakun proposed that winds would intensify in the upwelling or warm season; i.e., May to August in the Northern Hemisphere and November to February in the Southern Hemisphere. Therefore, we categorized each trend based on the months averaged for its calculation: "warm season" or "annual" (all months). Bakun surmised that there would be latitudinal variation in wind trends and predicted that the most substantial intensification would be in the "core" of each EBCS. Therefore, to test for spatial heterogeneity in wind trends, we included absolute latitude in our models (*9*). We compared results from observational data and model-data reanalysis products, because previous research has shown different trends among these data types (*10*, *11*).

We used logistic regression to model the consistency of wind trends with the Bakun hypothesis. Although all studies included in our analysis undertook formal statistical analysis, they used different analyses and statistical approaches and also used a range of significance levels (0.01 to 0.10), many of which were reported only categorically (*9*). Consequently, we used a qualitative approach (table S3) in which we down-weighted nominally nonsignificant trends to half the weight

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of nominally significant trends. We restricted logistic regression models to two simultaneous explanatory variables per model, one of which was "ecosystem." We did not attempt to adjust for non-independence of related coastal winds time series; caution is therefore warranted in interpreting the results of our meta-analysis.

Classically, four EBCSs are recognized (Fig. 1), but because upwelling-favorable winds are driven by different continental pressure systems in the Iberian and North African regions of the Canary Current (*11*, *12*), we separated these regions for analysis. Overall, we found that published papers support wind intensification in three out of five upwelling ecosystems over the past six decades. For the California and Humboldt systems, warm-season analyses were significantly more likely to show wind intensification (i.e., log-odds ratios > 0; $P < 0.001$; table S5) than were annually summarized data. For the Canary ($P = 0.170$) and Iberian ($P = 0.357$) systems, warm-season winds were as likely to be intensifying as not (table S5). Studies in the Benguela system, although exclusively based on annually summarized data, reflected a greater likelihood of intensifying winds ($P = 0.011$). Studies of annually summarized data in other systems failed to detect wind intensification (Fig. 1). In contrast, annual data in the Canary ($P = 0.018$) and Iberian ($P < 0.001$) systems showed greater likelihood of weakening than of strengthening wind patterns. Overall, the likelihood of detecting a positive trend in winds was 5.9 times higher for warm-season data than for annual data ($P < 0.001$; table S5).

The probability of detecting intensifying winds was dependent on data type (tables S4 and S5; Benguela excluded because all data are model-data reanalysis products). Studies based on direct observations were significantly more likely to detect intensifying than weakening winds for the California ($P = 0.002$), Humboldt ($P < 0.001$), and Canary ($P < 0.001$) systems, as were studies of model-data reanalysis winds in the California system ($P = 0.009$). In the Iberian and Canary systems, model-data reanalysis products were more likely to detect weakening winds ($P = 0.004$ and $P = 0.002$, respectively). Because there were three times more annual than seasonal studies using model-data reanalysis products and almost four times more seasonal than annual studies using observational data, these findings concerning season and data type are not independent (*9*).

Within systems, the likelihood of a study detecting wind intensification increased significantly ($P = 0.004$) with absolute latitude (Fig. 2 and tables S4 and S5). Wind intensification was found across most latitudes for the Benguela (poleward of 20°S) and California systems (poleward of 32.5°N), as well as over the southern portion (poleward of 14°S) of the Humboldt (Fig. 2) system. Weakening winds were found at most latitudes for the Iberian system and over the southern half (equatorward of 23°N) of the Canary system.

To test the sensitivity of the conclusions to our treatment of nonsignificant trends, we reexamined the data after categorizing all nonsignificant trends as opposed to the wind intensification hypothesis. Results of this conservative approach remove support for long-term increases in upwelling intensity (fig. S1). However, we consider our original approach (categorizing all positive trends as supportive of the wind intensification hypothesis and a priori down-weighting nonsignificant trends) to be most appropriate, because nonsignificant trends contain information, albeit with less confidence than significant trends. Further sensitivity tests show that (i) categorizing nonsignificant trends as equivocal (i.e., essentially removing these trends from the meta-analysis) or (ii) equal weighting across significant and nonsignificant trends (tables S6 and S7) produces results that support our a priori approach of down-weighting nonsignificant trends [fig. S1 (*9*)]. In summary, based on our assumptions and approach, observational and warm-season

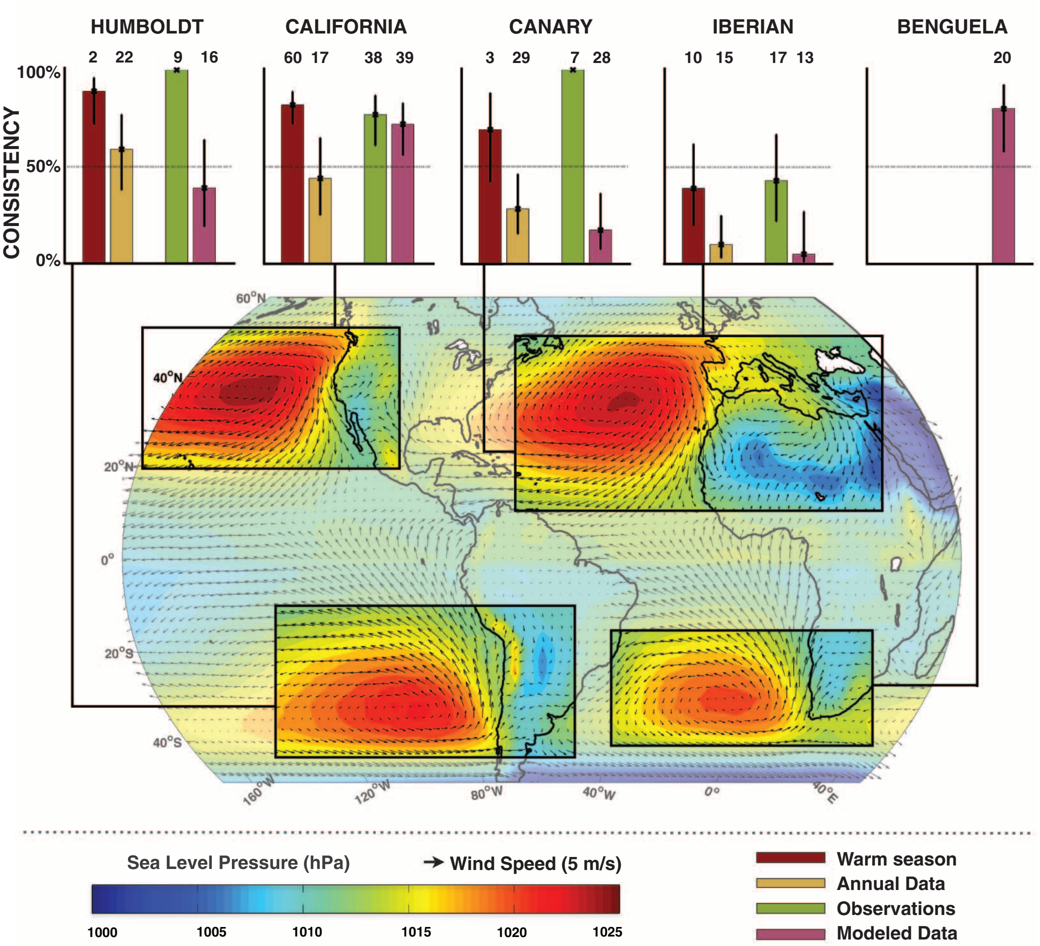

Fig. 1. EBCSs of the world showing warm-season spatial climatologies of sea-level pressure and surface wind fields based on the NCEP/NCAR (National Centers for Environmental Protection/National Center for Atmospheric Research) model-data reanalysis product. These are estimates from logistic regression of consistency with the wind intensification hypothesis; bars show the estimated probability (± 95% confidence intervals). Numbers above the bars denote the number of trends contributing to each point estimate and confidence interval. The dashed horizontal line denotes the null hypothesis of equal probability of increasing or decreasing winds.

data provide support for wind intensification in the California and Humboldt systems, as do model-data reanalysis products from the Benguela system and observational time series from the Canary system (*11*). Results for the Iberian system were contrary to the hypothesis, with contemporary winds weakening, corroborated by one of the recent studies published after our meta-analysis was completed (*12*). In general, annually averaged wind trends do not support intensification, highlighting that some of the disagreement in previous studies can be resolved by considering winds during warm (upwelling) seasons only, as originally specified by Bakun.

Model-data reanalyses and observational data showed some contradictory results. An exception was found for the California system, where both data types supported the hypothesis. This is probably due to the high density of observational records included in this well-measured system (*9*, *10*, *13*). Changes in instrumentation and time period covered, as well as natural (interannual and lower-frequency) climate variability, may be sources of bias in our meta-analysis. Most time series examined (91%) cover the period from the late 1940s to mid-2000s. By integrating almost 200 trend analyses, the sensitivity of our results to natural interannual variability and changes in instrumentation may have been reduced. The choices of study period and duration (*9*) nonetheless remain sources of uncertainty. We examined study duration in some detail (tables S4 and S5), but results were equivocal. In the Pacific systems, study duration had little effect on reported wind trends. In the Atlantic sector, there was a negative relationship between reported trends and study duration (fig. S2). It is clear that study duration and period of study are both unresolved factors that contribute to uncertainty in documented patterns of change both in the literature and in this meta-analysis. Variations in study duration and period also complicate the attribution of wind trends to anthropogenic climate change versus low-frequency climate variability, which influences wind intensity at interannual to multidecadal scales (*14*, *15*). The time series amassed to date and analyzed here are short relative to the time frame needed to differentiate between natural climate variability and anthropogenic forcing. Furthermore, the paucity of spatially comprehensive observations challenges attempts to clearly distinguish the impact of natural low-frequency variability from anthropogenic change. These are issues that require further investigation as longer coastal-wind time series become available.

In addition to variation among systems, we found an increased likelihood of wind intensification at higher latitudes within most systems. This may reflect stronger warming trends observed toward the poles than the equator (*16*). An exception is the Iberian system, which is driven by a relatively weak continental low over Europe. It is possible that further analyses of wind trends at subannual scales in that system might reveal different trends than those described here, because the region is strongly influenced by the North Atlantic Oscillation (NAO), although the NAO may affect coastal upwelling there most in the fall and winter (*11*, *12*, *15*, *17*).

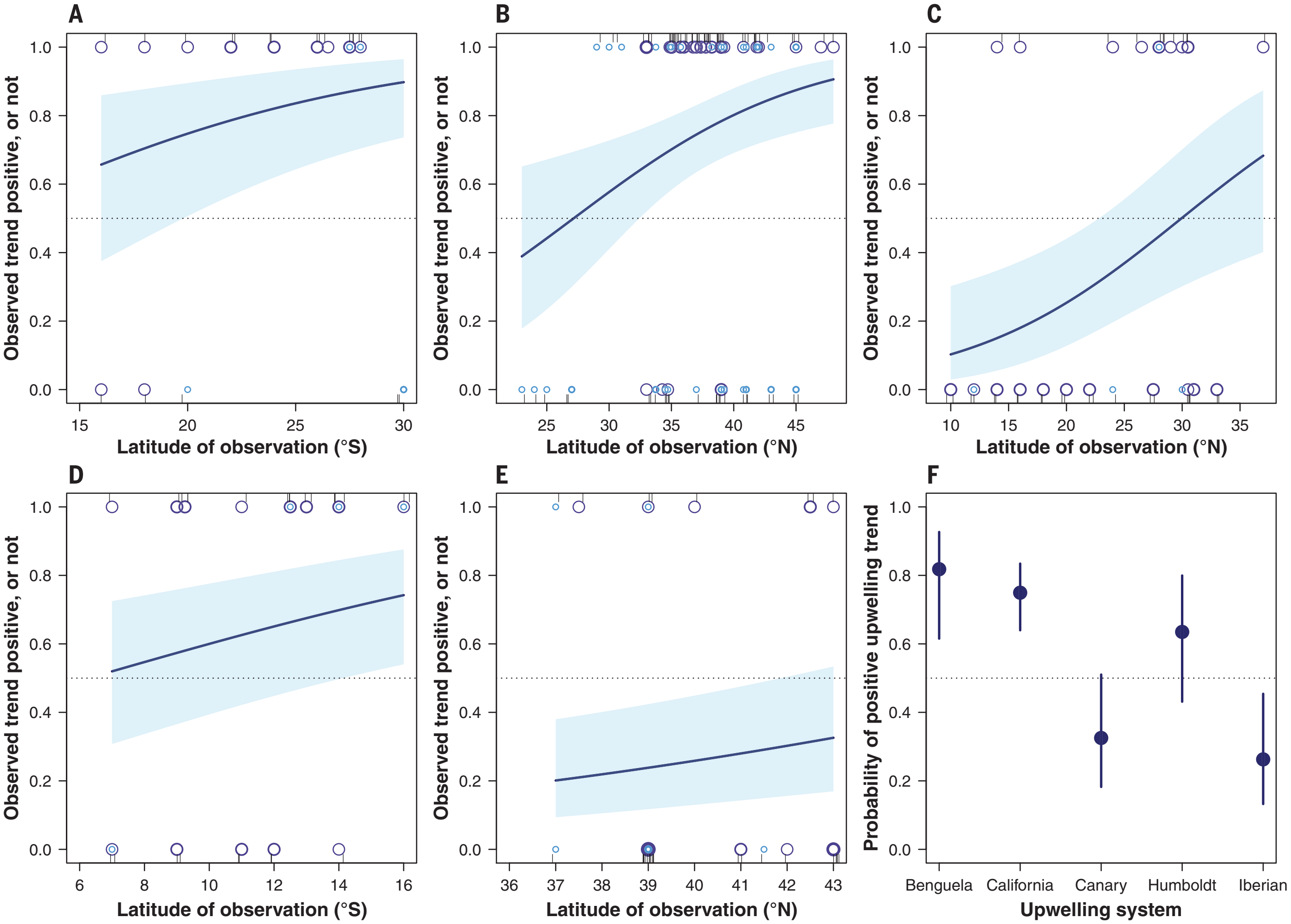

Fig. 2. Effect of absolute latitude by system. (**A**) Benguela, (**B**) California, (**C**) Canary, (**D**) Humboldt, (**E**) Iberian. Open circles represent trends in wind time series as reported in the literature (0 = weakening; 1 = strengthening); nonsignificant trends (light blue) are scaled to half the size of significant trends (dark blue). The weight of the circle outline is scaled to sample size at a given latitude. Tick marks adjacent to each circle indicate the latitude of each data set, with slight adjustments to emphasize the number of observations at any given point. The solid line represents the model fit; the shaded area is the asymptotic 95% confidence envelope. (**F**) Consistency with wind intensification (including 95% confidence intervals), as calculated across all latitudes within each of the five ecosystems.

Wind intensification in the California, Benguela, and Humboldt ecosystems could benefit marine populations by increasing nutrient input into subtropical euphotic zones if primary production is nutrient-limited. Large increases in wind strength, however, could be detrimental by disrupting trophic interactions (*18*), causing transport of planktonic organisms off continental shelves (*19*), or increasing acidic or hypoxic waters in shelf habitats (*4*, *5*). Although positive trends in coastal chlorophyll-a concentration off California and elsewhere (*20*) conform to the wind trends described here, there is no reason to assume that these changes will translate into increases in productivity across intermediate and higher trophic levels, although a recent study linked wind increases to improvements in albatross foraging efficiency and productivity (*21*). If new primary production constrains fisheries (*22*), greater primary productivity could enhance food production. However, ocean warming could counter stronger upwelling by increasing stratification (*23*), making it difficult to forecast ecological responses. Moreover, given the sensitivities of different species to the seasonality of upwelling (*24*, *25*), population variability might be linked to shifts in the phenology of upwelling as much as to changes in amplitude (*26*). Changes in the phenology of upwelling-favorable winds may also affect the trends within and across ecosystems described here. Ultimately, the sensitivity of observed wind trends to latitude, data type, season, and time-series duration demonstrated in this meta-analysis highlights the need for sustained high-quality observations of coastal winds and emphasizes the complexity of forecasting the consequences of wind intensification for ecosystems.

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SUPPLEMENTARY MATERIALS

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EARTHQUAKE DYNAMICS

Mapping pressurized volcanic fluids from induced crustal seismic velocity drops

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Volcanic eruptions are caused by the release of pressure that has accumulated due to hot volcanic fluids at depth. Here, we show that the extent of the regions affected by pressurized fluids can be imaged through the measurement of their response to transient stress perturbations. We used records of seismic noise from the Japanese Hi-net seismic network to measure the crustal seismic velocity changes below volcanic regions caused by the 2011 moment magnitude (M_w) 9.0 Tohoku-Oki earthquake. We interpret coseismic crustal seismic velocity reductions as related to the mechanical weakening of the pressurized crust by the dynamic stress associated with the seismic waves. We suggest, therefore, that mapping seismic velocity susceptibility to dynamic stress perturbations can be used for the imaging and characterization of volcanic systems.

Large volcanic eruptions are preceded by long-term pressure buildup in volcano magmatic and hydrothermal systems. Therefore, knowledge of the extent and state of these pressurized volcanic fluids at depth will help in the better anticipation of future eruptions. In particular, seismic tomography is often used to delineate volcano-feeding systems at different scales (*1*, *2*). However, a major difficulty of traditional seismic imaging of volcanoes is that the geological contrasts of the host rock might dominate the final tomographic images, which are only partially sensitive to the content and state of volcanic fluids (*3*).

Recent geodetic observations have shown that volcanic areas are characterized by anomalous responses to crustal deformation induced by large earthquakes, as demonstrated by the subsidence of volcanoes in Chile and Japan after the 2010 Maule and 2011 Tohoku-Oki earthquakes (*4*, *5*). This sensitivity to strong coseismic deformation and shaking is probably associated with the presence of pressurized hydrothermal and magmatic fluids at depth in a fractured medium. We explored the responses of volcanoes to transient stress perturbations by investigating the temporal evolution of crustal seismic velocities in Japan in response to the seismic shaking and deformation caused by the March 2011 moment magnitude (M_w) 9.0 Tohoku-Oki earthquake.

The Hi-net, Japanese high-sensitivity seismograph network, is among the densest in the world; thus, the 2011 Tohoku-Oki earthquake remains the best-recorded large earthquake to date. It was associated with large, widespread static ground deformation and ground shaking (Fig. 1). In this study, we used seismic noise-based monitoring (*6*) to characterize the response of the upper crust to the coseismic shaking and deformation caused by the earthquake. We analyzed 1 year of continuous seismic records from a portion of the dense Hi-net seismic network (600 stations, as shown in the inset to Fig. 1A), spanning from 6 months before to 6 months after the earthquake occurrence.

We computed the daily vertical-vertical noise cross-correlation functions using a processing scheme that minimized the effects of the strong aftershock activity that followed the Tohoku-Oki

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Climate change and wind intensification in coastal upwelling ecosystems

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