Fortnightly Oceanic Tidal Mixing in the Lombok Strait and Its Impacts on Lower Level Atmosphere

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Abstract

Indonesian seas provides the only ocean pathway connecting the tropical Pacific and Indian Oceans known as Indonesian Throughflow (ITF). The ITF plays an integral role in global ocean thermohaline circulation, directly impacting mass, heat and freshwater budgets of the Pacific and Indian Oceans with possible influences on the El Niño Southern Oscillation (ENSO) and Asian-Australian monsoons. Moreover, Indonesian seas are a center of atmospheric convection that drives the Walker Circulation. Hence, any changes in sea surface temperature (SST) within these regions will have profound impacts on high-impact downstream western hemisphere weather and climate events.

Tidal mixing in Indonesian seas plays an important role in regulating Pacific-Indian Ocean exchange, watermass transformation and air-sea interaction. Along its path, the ITF undergoes strong tidal mixing. Recent analysis of satellite SST (Ray and Susanto 2016) concluded that the largest fortnightly SST signals are localized to relatively small straits, channels and sills, while Banda shows little fortnightly SST signal, consistent with in situ microstructure measurements finding weak mixing in Banda Sea (Alford et al., 1999).

Strong tidal currents in and around the narrow straits of the Nusa Tenggara Islands, Indonesia, affect ocean SST via non-linear tide-induced mixing. A fortnightly spring–neap cycle in tidal currents can induce a similar cycle in SST, which has been observed to occur in and south of Lombok Strait. An atmospheric response to the fortnightly SST cycle which is detected in relative humidity and air temperature measurements at Bali. The fortnightly cycles in both the ocean SST and the Bali atmospheric data have a strong seasonal cycle, with peak signals occurring during boreal summer.

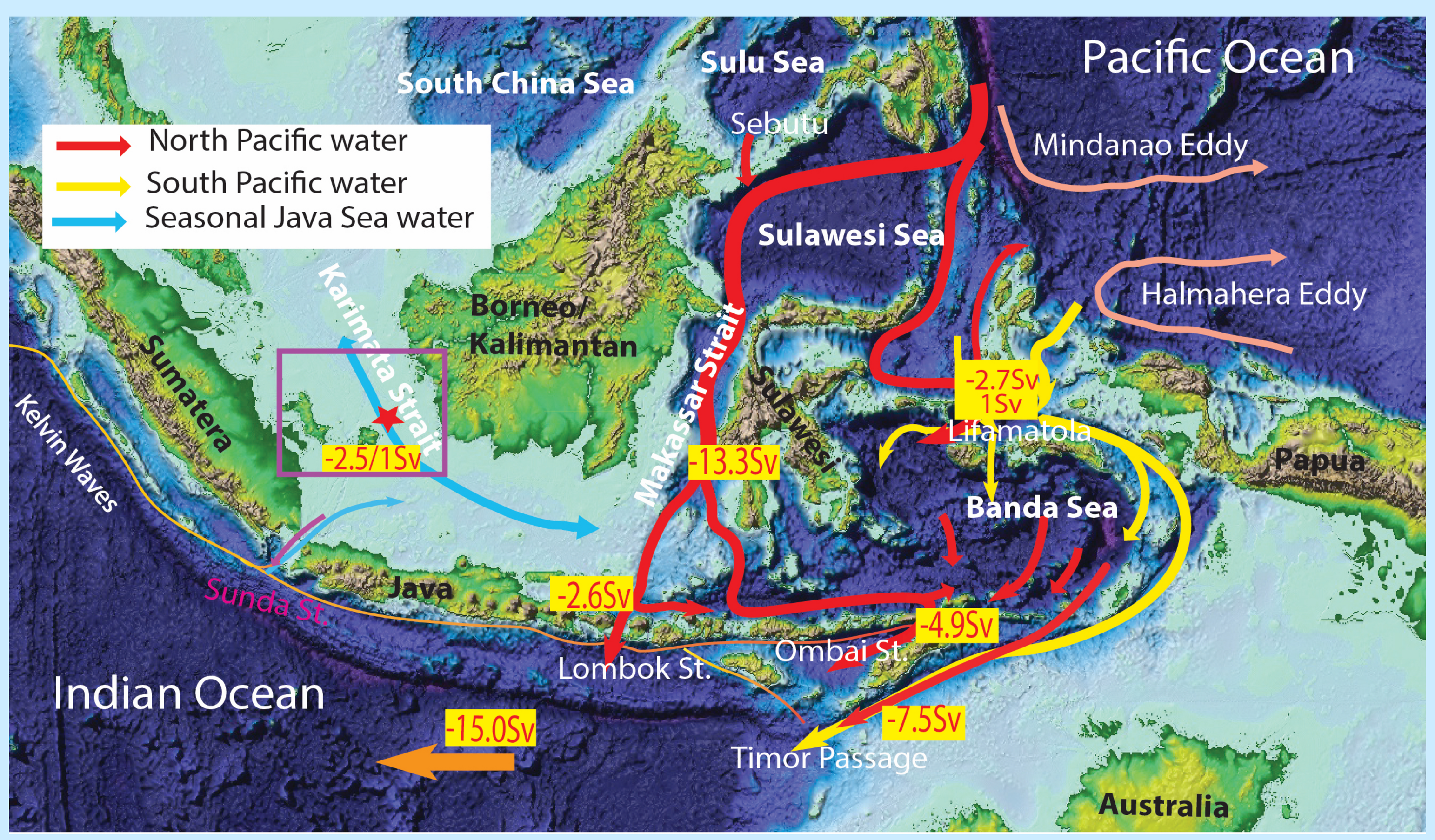

Figure 1. Indonesian throughflow (ITF) pathways from the Pacific to the Indian Oceans (Susanto *et al.,* 2016)

1. Data

- Multi-Ultra High Resolution Sea surface Temperature (Chin et al., 2013; 2017).
- The Bali meteorological data were obtained courtesy of Dr. Andri Ramdhani from the Agency for Meteorology, Climatology, and Geophysics, Indonesia.
- Bali temperature data are included in the Global Historical Climatology Network database from the NOAA National Climatic Data Center.
- Benoa tide gauge data from the Geospatial Information Agency (BIG), Indonesia.

2. Tidal Mixing Signatures in SSST of Indonesian Seas

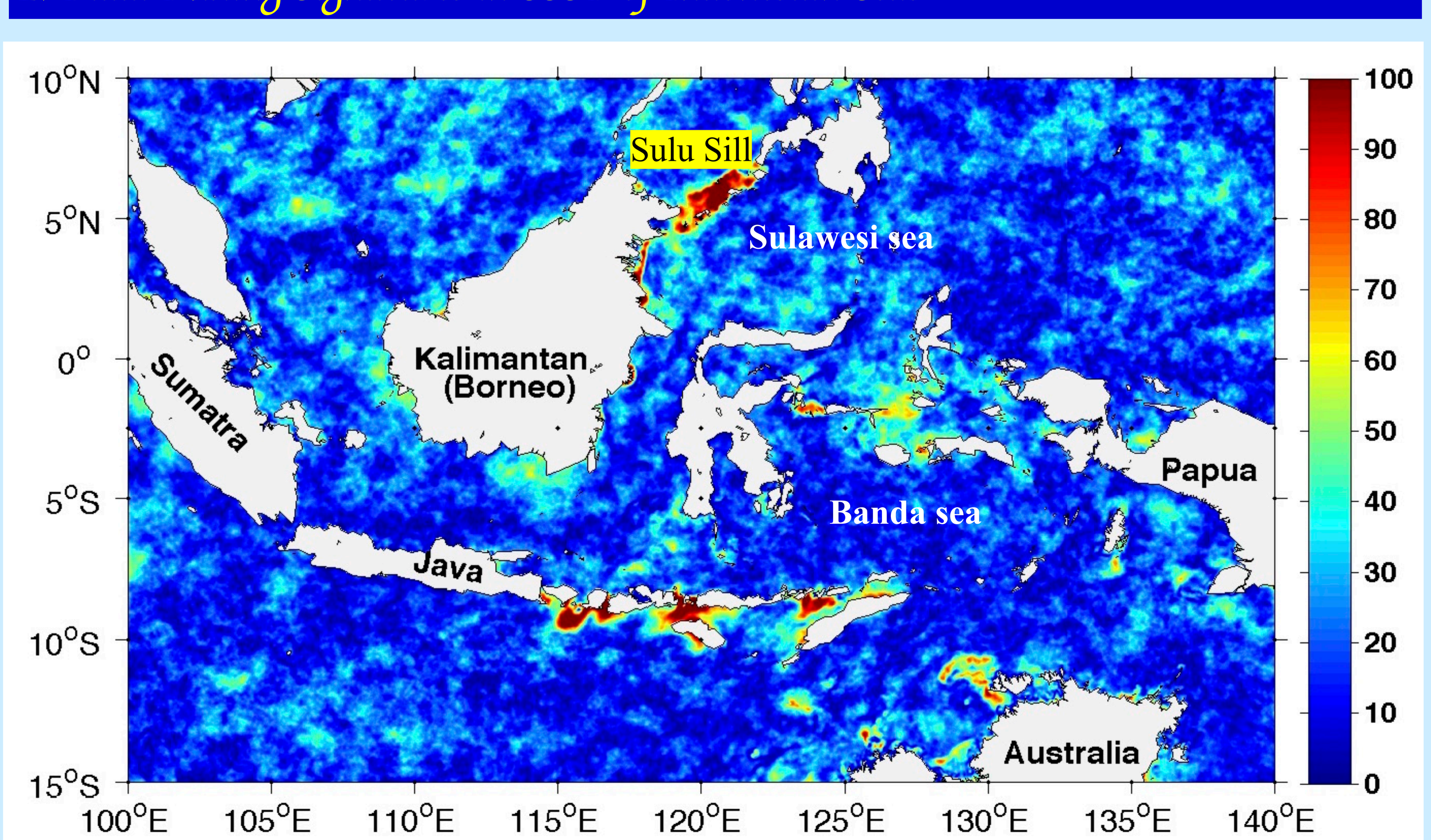

Figure 2. Estimates of amplitude (in millikelvin) of the spring-neap (MSf) tidal component in sea-surface temperature, extracted from over 12 years of MUR-SST data (Ray and Susanto, 2016)

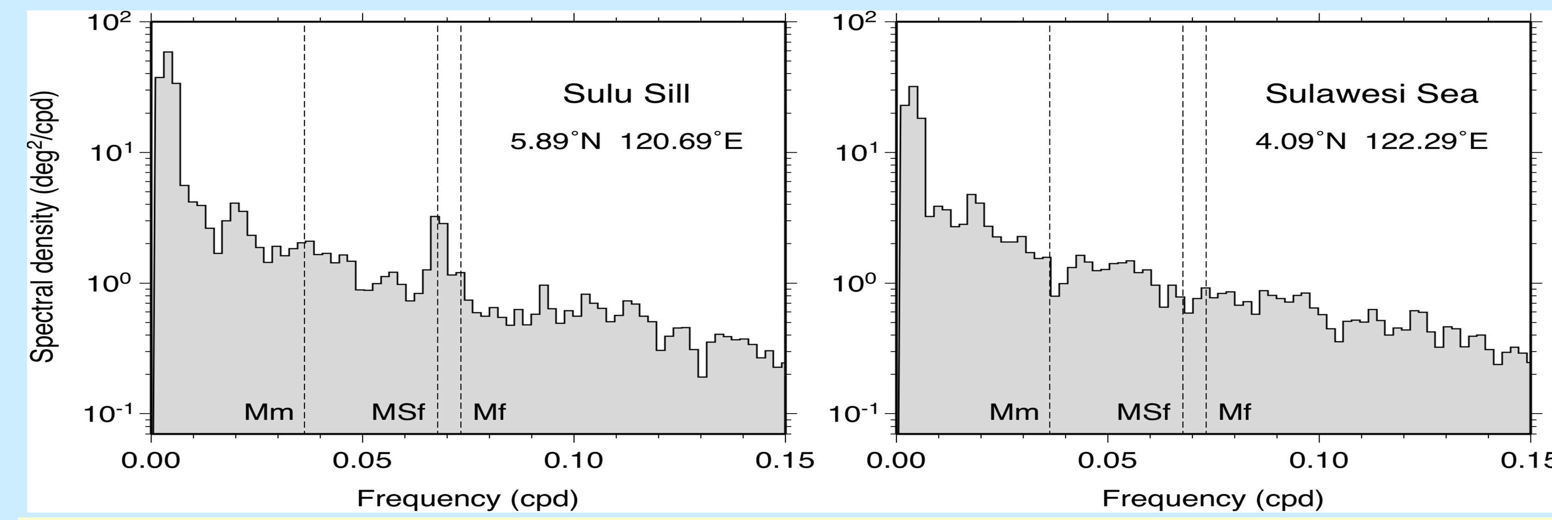

Figure 3. SST spectra based on 12 years of daily MUR-SST data at (LEFT) a location along the southern boundary of the Sulu Sea where the MSf peak is pronounced and (RIGHT) in the interior of the Sulawesi Sea where the peak is missing. Labeled vertical dashed lines mark frequencies of the three long-period tides; the spectral peaks at far left occur at the annual and semiannual frequencies. Near MSf the background level is clearly below 1K²/cpd. With a frequency resolution of (12 y)⁻¹ this background thus corresponds to a noise level somewhat below 0.02 K (Ray and Susanto, 2016)

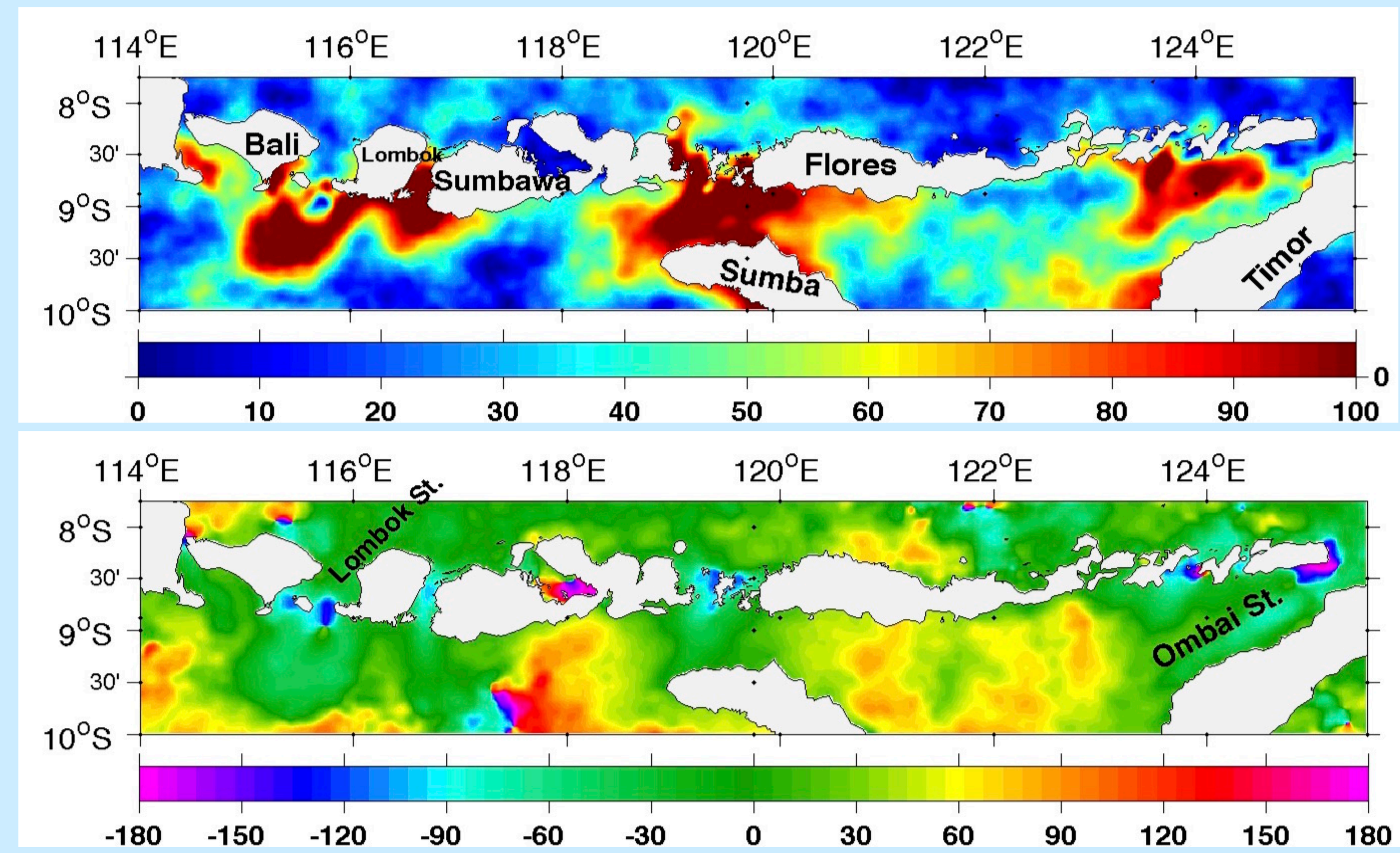

Figure 4. Estimates of (top) amplitude in millikelvin and (bottom) Greenwich phase lag in degrees, of the spring-neap (MSf) tidal component in sea-surface temperature, focusing on the southern part of the Nusa Tenggara Island chain. The regions of largest amplitudes all have phase lags of about -50°, but the phase lags within the major straits themselves are closer to -120°, or about 3 days earlier (Ray and Susanto, 2016)

3. A Fortnightly Atmospheric 'tide' caused by ocean tidal mixing in the Lombok Strait

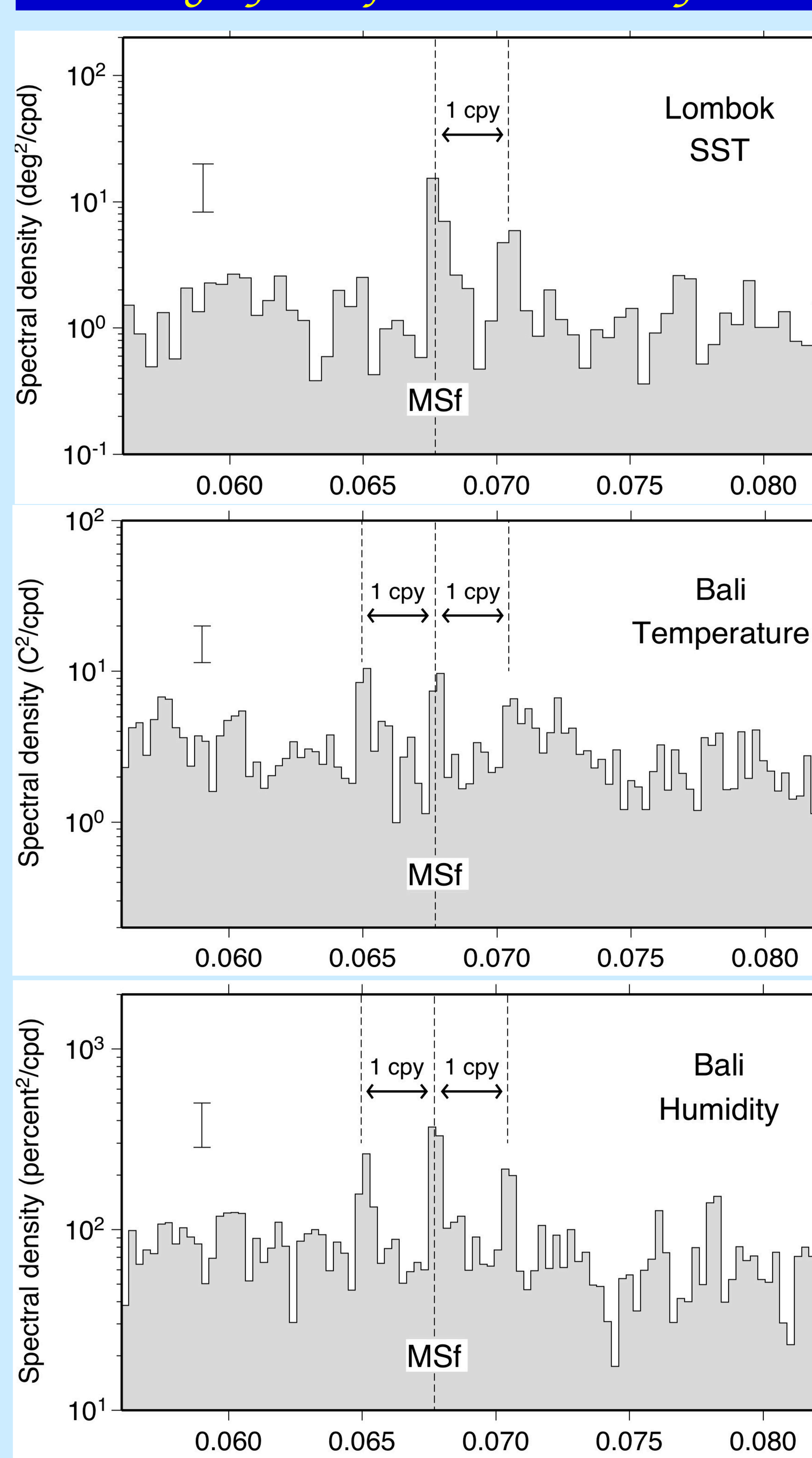

Figure 5. Near the fortnightly tidal band for spectra of SST (top) at a location south of Lombok Strait near the MSf maximum, (middle) air temperature at the Bali meteorological station, (bottom) relative humidity at Bali. A central MSf peak is apparent in all three spectra, as are 1-cpy sidelines. The SST spectrum, being based on a shorter time series, has coarser frequency resolution than the Bali meteorological data. Error bars give 95% confidence interval for any peak relative to background noise level (Ray and Susanto, 2019)

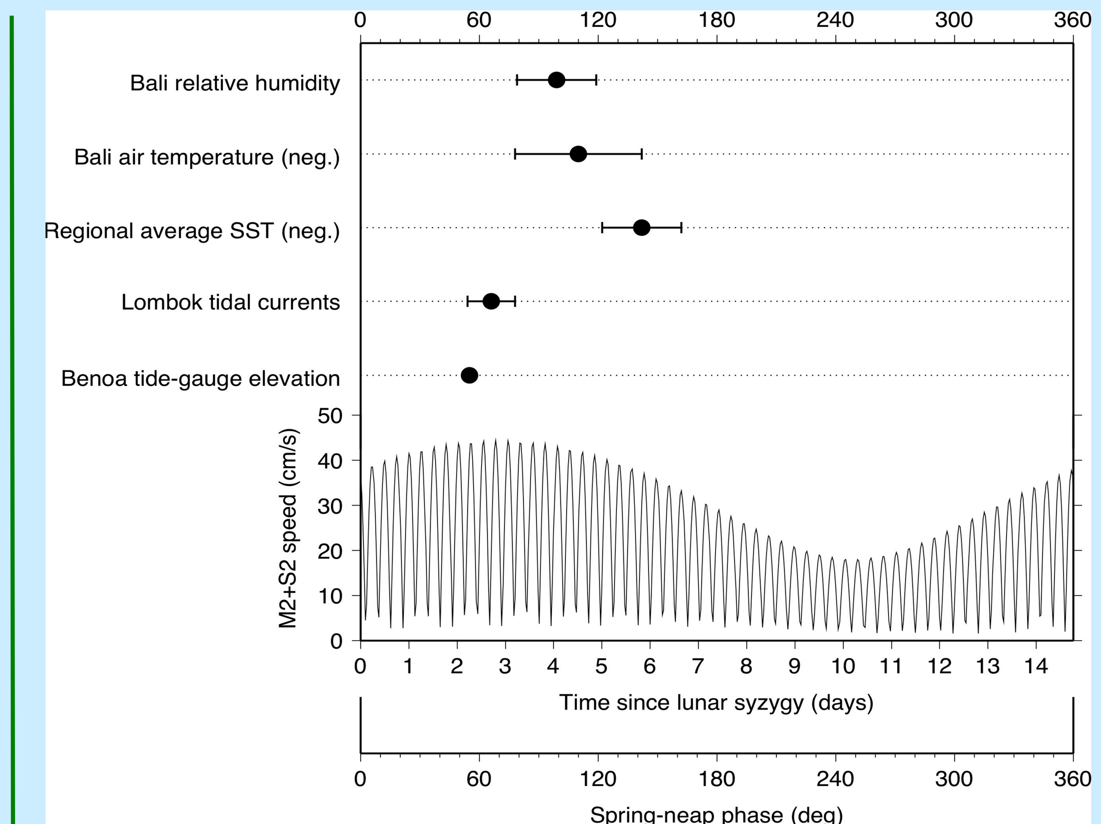

Figure 6. MSf phase lags, i.e., times within a spring–neap cycle of (top to bottom): maximum relative humidity at Bali; minimum air temperature at Bali; minimum SST in a region surrounding Lombok Strait; maximum tidal current speeds within Lombok Strait; and maximum spring-tide elevations at the Benoa tide gauge. Uncertainties represent $\pm 2\alpha$. The tidal semidiurnal currents are extracted from the barotropic finite-element model FES2014, which are drawn out explicitly in the lower panel (Ray and Susanto, 2019).

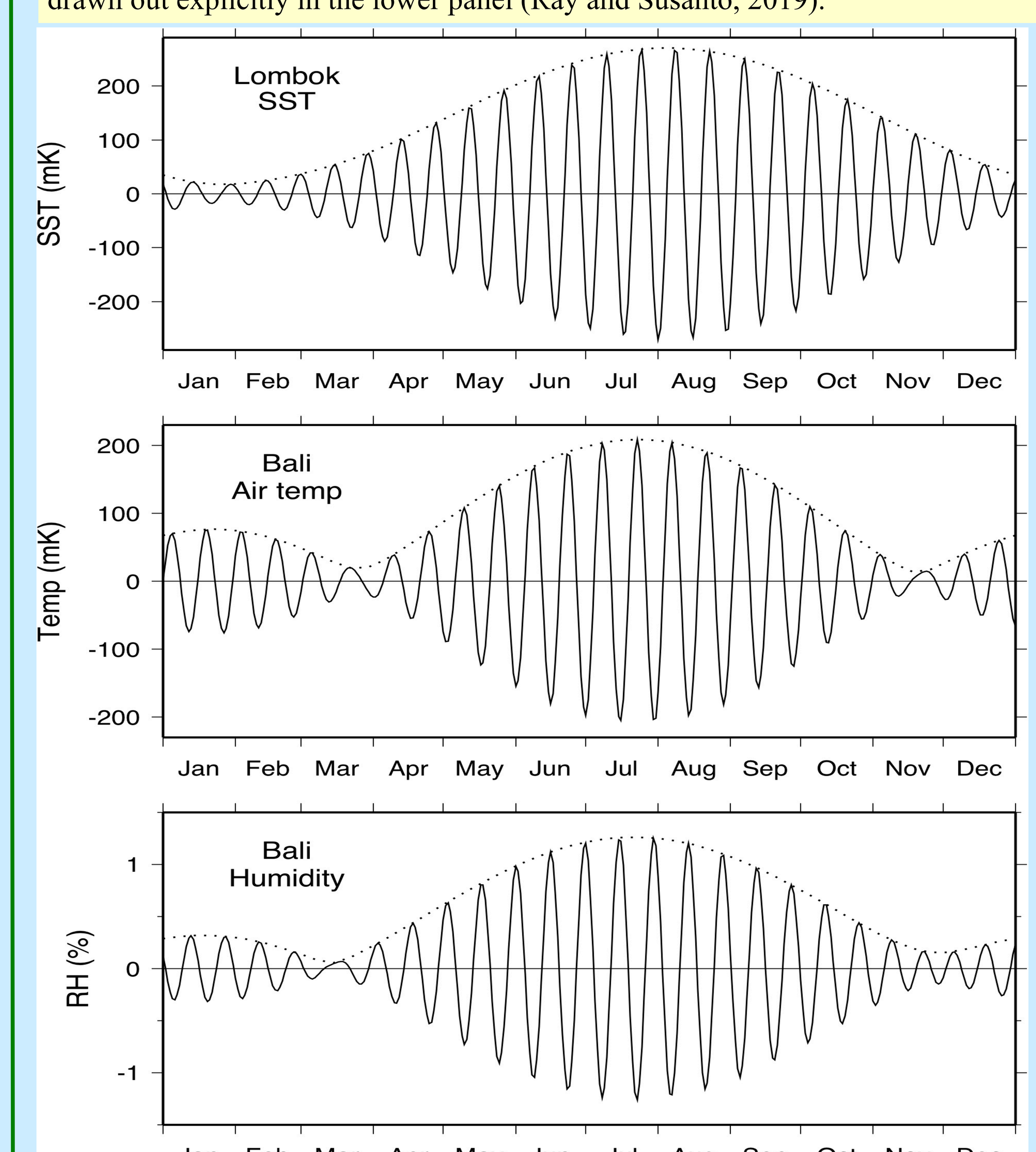

Figure 7. Seasonal variations of the fortnightly oscillations in SST south of Lombok Strait and in Bali air temperature and Bali relative humidity. The dotted lines delineate the seasonal envelope of the fortnightly signals. The fortnightly signals all peak during boreal summer (Ray and Susanto, 2019).

5. Conclusions

- ✓ Modern satellite sea-surface temperature data clarify tidal mixing signatures in Indonesian seas.
- ✓ Tidal mixing in Indonesian seas is particularly important because it plays a vital role in regulating Pacific-Indian Ocean exchange, water-mass transformation and air-sea interaction.
- ✓ Spring-neap SST signals are mostly localized to straits and sills; are not evident in the deep Banda Sea. Major straits of the Nusa Tenggara Island chain display strong, complex SST mixing signatures.
- ✓ The ultrahigh resolution SST data could be of great utility in mapping out connections between barotropic-to-baroclinic tidal conversion and locations of greatest tidal mixing. Such efforts should be invaluable in attempts to devise better mixing parameterizations for general circulation models.
- ✓ It is surely possible that tidal mixing can occur without a spring-neap modulation near the surface. It would then fail to be detected in a tidal analysis for MSf.
- ✓ These oceanic SST signals can generate a small, but detectable, signature in meteorological observations on Bali, a peculiar kind of atmospheric tide with fortnightly periodicity. The signals are most apparent during boreal summer.
- ✓ The fortnightly signals detected in SST and in surface air temperature and humidity are very small; they are easily overlooked and can surely be neglected in most discussions of Indonesia's climate.
- ✓ Follow-up study may better reveal the connections between regional tidal currents and local meteorology, including why the MSf humidity signals are so much more pronounced than the temperature signals, why they are 180° out of phase, and how the signals change over time.

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