Abstract Compilation
KEYNOTE TALKS
Typhoon Rapid Intensification with 200 PVU Convective Potential Vorticity Tower in Numerically Simulated Supertyphoon Haiyan (2013)

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The present study examines the inner core dynamics of Supertyphoon Haiyan (2013) undergoing rapid intensification (RI) with a 2-km resolution cloud-resolving model simulation from the non-hydrostatic Cloud-Resolving Storm Simulator (CReSS). The results highlight the important roles of the potential vorticity (PV) tower and PV-mixing processes around the inner core on RI through a boundary layer (BL) linkage. At the low level in the simulated storm, the PV field reveals an elliptical and polygonal-shaped eyewall during RI onset. Then, the PV changes to a more monopole shape in the lower troposphere during the later period of RI. The PV budget analysis confirms the importance of PV mixing at this stage, i.e., the asymmetric transport of diabatically generated PV to the storm center from the eyewall and the ejection of PV filaments outside the eyewall. The piecewise PV inversion (PPVI) further indicates that PV mixing accounts for about 50% of the central pressure fall during RI onset. The decrease of central pressure enhances the symmetric BL radial inflow. The radial inflow leads to the increase of tangential wind speed through the inward advection of absolute angular momentum. The enhanced radial inflow leads to the contraction of the radius of maximum wind (RMW). The nonlinearity of the BL inflow forms a near shock structure near the eyewall, i.e. the dramatic decrease of radial inflow in a short distance, forms a strong BL updraft up to 20 m s\(^{-1}\) strength. Moreover, the dramatic decrease of the radial inflow leads to a significant decrease in the tangential wind which is with very large shear vorticity. The shock formation region near the eyewall is thus with a strong updraft and large vorticity coupled together to form the convective PV tower inside the RMW. Our simulation with 500 m resolution produces a PV tower of 200 PVU. The simulation is in general agreement with observations.
From ophiolite emplacement to arc magmatism and intra-arc basin formation: A peek into the evolution of North Luzon

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The eastern and western seaboards of North Luzon are characterized by emplaced ophiolites and melanges. North Luzon has evolved from a primitive island arc with a marginal basin substratum to a mature island arc as exposed in the Baguio Mineral District (BMD). The Mankayan Mineral District (MMD) sediments show oceanic island arc affinity consistent with the BMD sediments suggesting a common geological history. Arc splitting (Sierra Madre Range on the east and Cordillera Central on the west) resulted in an intra-arc basin (Cagayan Valley Basin). At the southernmost tip of the failed rift, alkali magmatism, mineralization and associated sedimentary rocks (e.g., Mamparang Formation) are found. Whole rock geochemical data from the Oligocene Mamparang Formation clastic rocks reveal quartzose sedimentary provenance and deposition in an active continental margin. Trench retreat associated with slab rollback caused the rift initiation as opposed to slab rollover-related trench advance which causes crustal shortening (Xue et al. 2022). Fast subduction, instead of a slow subduction, explains the relatively narrow Cagayan Valley rift basin (Erdos et al. 2022). Furthermore, field geological and temporal evidence suggests that the Cagayan Valley Basin rift opening is related to the proto-Philippine Sea Plate subduction. The subduction of the proto-Philippine Sea oceanic plate followed by the collision of the Benham Plateau led to arc polarity reversal (change from west-dipping subduction along the proto-East Luzon Trough to the east-dipping subduction along the Manila Trench during the late Early Miocene to Middle Miocene). The plateau collision could have been the trigger for the alkali rock-hosted mineralization in the southern part of the Cagayan Valley Basin. Alkali rock-related mineralization is usually related to tectonic upheavals. In terms of paleoclimate, the transition from Oligocene to Early Miocene, globally, is marked by a cold to warm transition. The Middle Miocene is characterized by warming followed by cooling during the Late Miocene to Early Pliocene. Our BMD and MMD sediment data set shows otherwise. The Oligocene to Early Miocene Zigzag Formation in North Luzon is depicted by a warm and humid environment transitioning to a cool and dry setting during the Middle to Late Miocene (Klondyke Formation). Climatic changes in this part of the world are attributed to a) changes in the interaction of the South Asia Monsoon with the Tibet-Himalayan Highlands, b) opening of the South China Sea, c) change in the source of dust that can affect ocean temperature, d) orbital forcing and
precession controls, and e) migration of the inter-tropical convergence zone (ITCZ), among others. We argue that the recognized paleoclimate in North Luzon during the Oligocene to Miocene is a function of the position of the ITCZ, a major source of precipitation. Lastly, aside from understanding the geological evolution of this part of the Philippine island arc system, this review can shed light on the factors related to the observed mineralization (i.e., alkaline to calc-alkaline hosted) and geological hazards.
ORAL PRESENTATIONS:
Meteorology
Central Weather Bureau (CWB) has been investigating the tropical cyclone (TC) forecast skills beyond 7 days since 2008. A real-time TC monitoring system was developed to objectively detect the TCs in the 21-member NCEP GEFS (Global Ensemble Forecast System). This system has been upgraded to “CWB TC Tracker 2.0” in 2020 by extending the forecast lead-time to four weeks. Furthermore, multiple global ensemble models are utilized in the new system. In addition to the NCEP GEFSv12 (FV3-based), the CWB TC Tracker 2.0 has included the real-time forecasts from the 51-member ECMWF ensemble forecast system (ECEPS), NCEP Climate Forecast System (CFSv2), and the CWB 1-tier climate forecast model (CWB1T1).

The development of CWB TC Tracker 2.0 will be introduced in the meeting. Also, weeks 1-4 TC forecast skills in the western North Pacific using the ECEPS and NCEP GEFSv12 will be presented. Weeks 1-4 TC formations and subsequent tracks are objectively detected, and the forecast skills are evaluated under different large-scale environments (e.g., monsoon index and MJO). To assist in identifying the potential false alarms, a spatial-temporal track clustering technique is implemented to identify similar member vortex tracks and obtain the corresponding ensemble mean tracks. Through the Taiwan-Philippine VOTE (Volcano, Ocean, Typhoon, and Earthquake)-Meteorology project, the forecasters at CWB and PAGASA (Philippine Atmospheric, Geophysical and Astronomical Services Administration) are now jointly using the CWB TC Tracker 2.0 as their main tool for TC forecasting in weeks 1-4.
Time-lagged Ensemble Quantitative Precipitation Forecasts for Three Landfalling Typhoons in the Philippines using the CReSS Model

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In this study, high-resolution quantitative precipitation forecasts (QPFs) in lagged runs by a cloud-resolving model are evaluated for three typhoons in the Philippines: Manghkut (2018), Koppu (2015), and Melor (2015) that hit northern Luzon, central Luzon, and the middle section of the Philippine Archipelago, respectively. Using categorical scores, the model QPFs are verified against 56 gauge observations on land over the Philippines in the first part of this study, and against the Global Precipitation Measurement (GPM) satellite rainfall retrievals (also covering nearby oceans) in the second part in the same way, allowing for a comparison between the results against the above two different data sources. For each typhoon, rainfall valid at a selected 24-h period and the whole event (48 or 72 h) are examined. For 24-h rainfall inside the short-range (lead time within 72 h), good QPFs (with a threat score of 0.2 or higher) against the satellite data are produced for Koppu at 200 mm by almost all runs, and at 100 mm by all runs for Mangkhut but only 22% of runs for Melor. At longer lead times, good QPFs at 100 mm were also produced by all runs for Koppu, half of runs for Mangkhut, and only 1 out of 16 runs for Melor. For the whole events (48 or 72 h), the QPFs are similarly the best for Koppu, followed by Mangkhut, and least ideal for Melor. The quality of the GPM data during the three typhoons are found generally good and suitable for QPF verification, and the results are more stable and thus more reliable for assessment in bias. However, the threat scores using the GPM drop lower at high thresholds and the results may become different from those against the gauges (Part I), which suggest much higher skill, particular for Koppu. Thus, the verification using rain gauges is still needed toward high thresholds, especially over mountain regions where satellite estimates tend to exhibit larger errors.
Many environmental catastrophes, like floods and landslides, happen mostly during the typhoon season in the Philippines. A good rainfall forecast is essential for the development of an early warning system that would mitigate the effects of such. One way to forecast weather, specifically the amount of rain, is the use of Numerical Weather Prediction or (NWP) model. Currently, most of the available NWP Model products are global products with low resolutions, resulting in unreliable forecasts in areas with complex terrains.

The main objective of this study is to downscale global products to a finer resolution using the Weather and Research Forecasting (WRF) Model. Specifically, run and provide daily 5-day weather forecasts in the province of Benguet, Philippines during “STS Florita” and validate the model's performance using available Automatic Weather Stations (AWS).

Monthly albedo, monthly Leaf Area Index (LAI), monthly vegetation fraction, annual mean deep soil temperature, terrain height, land use category, and soil categories were used as static geographical inputs to a specified grids (3km x 3km and 9km x 9km) and boundary condition in the study area. Global meteorological forecast dataset from NCEP Global Forecast System(in GRIB files), with initial weather conditions on 12 UTC forecast run on August 21, 2022 before “Florita” developed into a Tropical Depression, were incorporated into the grids. The simulation was run up to August 25, 2022 with daily intervals for both resolutions. The forecast results were post-processed and validated using Quantum GIS. Verification scores were used including R2, mean error (ME), mean absolute error (MAE), percent bias (Pbias) and root mean square error (RMSE). Notably, the model was able to predict the day when peak rainfall will occur. However, results showed that overestimations were evident during extreme events.
Providing Sub-Seasonal-to-Seasonal Multi-Model Grand Ensemble Tropical Cyclone Strike Probability Forecasts in the Philippines

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Tropical cyclone (TC) forecasts provided beyond the conventional short- to medium-range timescales can be beneficial for disaster-risk preparation and mitigation of TC-vulnerable countries like the Philippines. Here, we demonstrate that the Central Weather Bureau’s (CWB) TC tracking outputs derived from the NCEP Climate Forecast System version 2 (CFSv2), European Centre for Medium-Range Weather Forecasts Ensemble Prediction System (ECMWF), and NCEP Global Ensemble Forecast System version 12 (GEFSv12) can be used in providing TC strike probability forecasts over the Philippines for up to four-week lead time. TC tracks detected from each of the ensemble members (comprising a total of 86 individual members) were combined and used in the formulation of the grand-ensemble probability forecasts. Two years’ worth of TC forecasts covering the period from 06 October 2020 to 31 October 2022 over the region bounded by 0°-27°N and 110°-155°E were evaluated. Verification metrics show that the Week-1 TC forecasts are reliable and useful for decision-making. TC forecasts for Week-2 are also reliable but only up to 60% probability, while forecasts with 3-4 weeks lead time are reliable for probabilities less than 20% only. Results further show that, generally, forecasts for TCs with higher intensity tend to perform better than forecasts made for relatively weaker ones. These findings suggest that the multi-model grand ensemble used in this study can be used for further development and eventual operationalization of probabilistic TC strike forecasts over the Philippines at longer sub-seasonal-to-seasonal timescale.
The Philippine springtime (February-April) sub-seasonal rainfall extremes and extended-range forecast opportunity revealed in the S2S database

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During the first half month of April 2022, the Philippines experienced severe disasters associated with the weak but deadly tropical storm Megi that caused 214 deaths and the sinking of two ships. This prompted us to investigate the predictability of the springtime Philippine sub-seasonal scale rainfall extremes and to identify the forecast opportunity in the S2S prediction database. The results suggest that ENSO is the most influential climate driver for the sub-seasonal scale springtime (February-April) rainfall variability in the Philippines. MJO and equatorial Rossby (ER) waves can modulate the sub-seasonal rainfall extremes. The 15-day accumulated rainfall amount of the sub-seasonal peak rainfall events (SPRE) is higher during a La Niña spring, so is the occurrence probability of a extremely wet event. The wet extremes can be enhanced by strong MJO or equatorial Rossby (ER). For the April 2022 case, the S2S multi-model ensemble mean (MME) can successfully predict the extremity of the SPRE at least 10 days ahead, although both MJO and ER were weak during the occurrence period of the deadly SPRE. Thus the successful prediction was interpreted as a result of the predictability rooted in the rainfall variability driven by the La Niña event. Since the S2S prediction is built on the ENSO foundation, it is proposed to include the SPRE in the real-time extended-range forecast items to exploit the benefits of S2S prediction and applications.
Cold Surge Impacts on the Structure, Energy Budget, and Turbulence of the South China Sea Boundary Layer

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Episodic cold surges associated with the East Asia (EA) winter monsoon can penetrate deep into the South China Sea (SCS), enhance consequent tropical rainfall, and further strengthen the EA meridional overturning circulation (MOC). These cold surges can promote strong surface fluxes and lead to a deeper marine planetary boundary layer (PBL). However, there is a lack of boundary layer studies over the SCS, unlike many other well-studied regions such as the north Atlantic Ocean and the central-eastern Pacific Ocean. The disparity can lead to unrealistic boundary layer turbulence and energy transport such that the tropical convection and the EA-MOC are incorrectly represented. In this study, we use high resolution radiosonde data of temperature and humidity profiles over Dongsha Island to identify the PBL height (PBLH), mixed layer height (MLH), cloud base, and cloud top for the period of December-January-February (DJF) from 2010 to 2020. We combined ERA-5 large-scale condition data and surface fluxes, MERRA-2 cloud radiative effects, and radiosonde-derived PBL parameters to provide information for an energy budget analysis and turbulent diagnostics from the mixed-layer model from Nicholls (1984). Here we show a strong turbulent flux convergence of both heat and moisture over the SCS during cold surges, which leads to the presence of clouds over Dongsha Island (116.69E, 20.70N) and an associated lifting of the PBLH to ~2.0 km and MLH to ~1.0 km. The cold and dry horizontal advection is balanced by this vertical turbulent flux convergence in the energy budget. Overall, at post-surge the PBL is stable but mixed layer is unstable, which contrasts with the pre-surge stage that features a stable mixed layer and a conditionally unstable PBL. We anticipate our study will motivate more atmosphere-ocean joint observation and PBL-related studies over the Taiwan-SCS region, including on the propagation of intra-seasonal oscillation and tropical waves.
Impacts of East Asian Atmospheric Circulation modes by Indian Ocean Dipole (IOD) and ENSO states in summer and autumn

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This study focuses on the impact of different sea surface temperature variations of Indian Ocean and Pacific Ocean on the circulation in East Asia. It shows different types of circulation and precipitation phenomenon over East Asian and Taiwan area by 4 modes of IOD and ENSO extreme years. The Indian Ocean Dipole Mode Index (DMI) and Oceanic Niño Index (ONI) were used to identify four types of positive IOD without ENSO (p-IOD), positive IOD with ENSO (p-IOD/ENSO), negative IOD (n-IOD) and negative IOD with La Nina (n-IOD/La Nina).

The preliminary results show that anti-cyclone circulation over the eastern Indian Ocean and cyclonic circulation over the western North Pacific by p-IOD composite map. This cyclonic’s location is a key factor to dominate the precipitation characteristics of East Asia and Taiwan in the summer and autumn.

Second type of p-IOD/ENSO shows that anti-cyclonic circulation over the eastern Indian Ocean in autumn (SO) is stronger than p-IOD circulation pattern and more dryness over Taiwan in autumn.

Third type of n-IOD/La Nina shows a tendency to enhance the subtropical high with drier summer season over East Asia and Taiwan. In autumn, the cyclone circulation and southerly wind over East Asia will be strengthened, which induce the northward transport of tropical water vapor.

The four type of n-IOD shows a little humidity on Taiwan in the summer and autumn, while the main characteristics of the East Asian circulation are not significant.
Deforestation is a major issue affecting both regional and global hydroclimates. This study investigated the effect of deforestation in the Maritime Continent (MC) on tropical intra-seasonal climate variability. Using a global climate model with Madden–Julian Oscillation (MJO) simulations, we examined the effect of deforestation over the MC region by replacing the forest canopy with grassland. The results revealed that under constant orographic and land–sea contrast forcing, the modification of the canopy over the MC altered the characteristics of the MJO. We noted the amplification of the MJO and increases in wet–dry fluctuation and the zonal extent. We analyzed more than 100 MJO cases by performing K-means clustering and determined that the continuous propagation of the MJO over the MC increased in 35% and 61% of the total 110 cases in the control and deforestation experiments, respectively. This phenomenon was associated with more substantial vanguard precipitation, increased soil moisture, and a suppressed diurnal cycle in land convection. Furthermore, when the MJO convection was over the Indian Ocean (IO), we observed the enhancement of low-level moisture over the MC region in the deforestation experiment. Grassland surface forcing provides a thermodynamic source for triggering instability in the atmosphere, resulting in low-level moisture convergence. The MJO exhibited a stronger energy recharge–discharge cycle in the deforestation experiment than in the control experiment, and this difference between the experiments enlarged from the IO to MC.
The application of WaveWatch III wave nests model and currents interaction on Taiwan area

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Ocean in an area where the ocean current in the opposite direction of the waves, the current will affect and change the waves’ directions; then, the wave steepness will increase. These areas can easily lead to accidents for small and medium-sized ships. Therefore, the addition of ocean current into the wave model becomes critical. Four layers of regular grids with 0.5, 0.25, 0.1 and 0.025 degrees grid sizes respectively were built by using Wave Watch III model. The largest grid domain is the global model which covered from the latitude -70 to 70 degrees. The calculation of adding SCHISM flow model of the Central Weather Bureau on the 0.025-degree wave model only in January and August 2018 has been completed. The results show that the wave simulation will generate a maximum of about 10~20% difference in different seasons (January and August). Compared with buoys, the calculation result of wave height and period do not change significantly or improve with regions.
Asymmetric modulation of ENSO on TC activity affecting the Philippines

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Tropical cyclone (TC) activity affecting the Philippines in the October-December (OND) season exhibits asymmetric connections with ENSO, featuring active or inactive TC activity during El Niño or La Niña years. For active (inactive) TC activity over the Philippines, sea surface temperature (SST) anomalies exhibit a major warming around 170o-160oW (140o-130oW) that induces a large-scale convergent center in the tropical eastern Pacific and a tropical divergent center in the tropical western Pacific around 120o-130oE (130o-140oE). Via a Matsuno-Gill-type response to the divergent center in the tropical western Pacific, the Philippines are surrounded by an anomalous cyclone to the east and an anomalous anticyclone to the west (underneath an eastward-displaced anomalous anticyclone). For El Niño years with active TC activity, an anomalous cyclonic shear circulation enhances TC formation over the Philippine Sea and attract more TCs moving toward the Philippines. For El Niño years with inactive TC activity, the eastward-shifted anomalous anticyclone suppresses TC formation in the Philippine Sea, leading to reduced TC movement toward the Philippines. During La Niña years, active-TC type is associated with cold SST anomalies in the tropical eastern Pacific and the eastern Indian Ocean/South China Sea and warm SST anomalies between them in the western section of the tropical western Pacific. These SST anomalies induce a large-scale convergent anomaly centering around 140o-150oE and an anomalous cyclone extending from the Indian Ocean toward the Philippine Sea. TC formation increases in the Philippine Sea that are later steered by anomalous southeasterly flows of the anomalous cyclone to move toward the Philippines. For the inactive type, major SST anomalies appear as cold anomalies elongating in the tropical eastern Pacific and warm anomalies in the tropical western Pacific. These SST anomalies induce a large-scale convergent center centering around 120o-130oE that in turn causes a westward extension of the anomalous anticyclone to overlie the Philippines. TC formation is reduced in the tropical western Pacific, leading to reduced TC movement toward the Philippines.
Products of Seasonal Forecast for Supporting Water resources

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The Central Weather Bureau developed high-resolution space-time rainfall seasonal forecast products by a statistical downscaling method using ECMWF’s fifth generation seasonal forecast system (SEAS5) forecast products. This product is very useful for water resource decision-making of water resource management.

In terms of forecasts for the next six months, CWB designed six-category (by exceedance probability 0-10%, 10-30%, 30-50%, 50-70%, 70-90%, 90-100%) probability forecasts for reservoirs are developed by using the seasonal forecast ensemble model. The hindcast is also used to present the forecast reliability and model climatology. Forecast evaluation shows that the six-category probability forecasts are skillful in most reservoirs during April, September, and November. These products can provide more information compared to rainfall deterministic forecast and three-category (below-normal, normal, above-normal) probability forecast products.

Besides, CWB developed high resolution (~1km) drought indexes of SPI and SPEI and show drought early warning information to improve preparedness and decrease risks associated with crop and food loss. This real-time drought monitor system with 1-km grid rainfall observation data over Taiwan island is very useful for water resource agencies and agriculture.

It is worth mentioning that CWB changes probability to exceedance probability suitable for water resource management and shows six-category with confidence level by skill score during hindcast period. Right now, it’s an operational seasonal forecast system to serve water resource agencies by providing space probability products over reservoir areas to view forecast guidance.
Propose an operational wind gust forecast system with numerical weather prediction model and in situ observation

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In the present study, a wind gust forecast system was proposed for stations with numerical weather prediction model output (NWP) and observed wind gust data (OBS). In operation, the relationship between NWP and OBS (model-observed gust factor) could be successively updated using model predicted 10-m wind speed in correspondingly with the available observed wind gust. Since high variability of wind gusts around the complex topography in Taiwan, the model-observed gust factor was successively updated for independent stations. To successively update the model-observed gust factor, the training dataset of each station will include the latest 30-h paired observing wind gust and numerical weather prediction model output. Two methodologies including linear regression and micro-genetic algorithm were conducted to derive the model-observed gust factor and could provide the hourly wind gust forecast product.

The operational wind gust forecast system was 4-time daily updated for those gauges with hourly observed wind gusts. Wind gust forecast product was verified with 30 stations included around complex terrain in Taiwan. There are 2 months as well as 4 typhoon events being evaluated. Results show that the adaptive factor derived from Micro-genetic algorithm could further improve the wind gust forecast at the wind speed greater than 13.9 (m/s) which is equal to the beaufort wind scale 7. In addition to evaluating the proposed wind gust forecast system at 10-m wind gust observation, it was also applied to a wind tower at 100-m wind gust observation. Results also demonstrated the robustness of Micro-genetic algorithm to be used to describe the model-observed gust factor.
New operational S2S forecast system in Central Weather Bureau in Taiwan

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The Central Weather Bureau (CWB) global ensemble prediction system (GEPS) has been deployed to produce 45-day global ensemble forecasts with the aim of providing extended-range forecast services. CWB has scheduled the implementation of its next deterministic model CWB FV3GFS in the spring of 2023, and the upgrade of new CWB GEPS for S2s forecast is undergoing test and will be operated before autumn of 2023. The atmospheric model of the GEPS applies octahedral reduced Gaussian grid at a horizontal resolution of 28 km and includes 72 vertical layers with a model top at 0.1 hPa. Twenty Ensemble Kalman Filter (EnKF) members from data assimilation system of its new weather deterministic model (CWB FV3GFS) are used and Stochastic Perturbed Parameterization Tendency (SPPT) scheme is applied to enlarge ensemble spread. Results obtained from 20 30-day runs display significantly improved simulations in the first 2 weeks including ensemble root mean square errors and ensemble spread of geophysical height at 500 hPa, temperature at 850 hPa, and U-wind both at 850 hPa and 200 hPa.
Geomorphic and soil physical characterization of landslides in mineralized terranes in northern Luzon, Philippines


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In Benguet Province's mountainous areas, landslides caused by rainfall are frequent. Some of these disasters resulted in the loss of life and damage to properties (e.g., 2018 Typhoon Mangkhut landslide in Itogon). The research area is underlain by volcano-sedimentary strata that have undergone extensive alteration as a result of mineralization. As a consequence, there are numerous mining activities in the area, some of which are frequently linked spatially to slope failures in the mining zones. The geomorphological and detailed soil physical and mineralogical characteristics were studied in two different mineralized zones in the province i.e. Baguio and Mankayan mineral districts. Geomorphic features were analyzed using Geographic Information System utilizing the areas with mapped slope failures. Soil analyses, consisting of bulk and particle densities, soil texture, and Atterberg limits were carried out. Representative mineralogical composition of soils were also determined. Geomorphic characteristics in areas with landslide occurrences showed that elevation and aspect are variable. Slope failures occurred in areas with 400 to > 2001 masl with about 13% in 1400 to 1500 masl with almost equal distribution of slope failures in different aspects (i.e., NE,NW,SE,NW). More than 92% of the analyzed landslide areas have slopes classified as steep (22.5 - 45%) and very steep (45 - 90%) slopes. The soil densities and porosity values vary and exhibit the influence of mineralization (silicic alteration), which results in a larger sand percentage and significantly lower porosities. Samples have variable plasticities but are mostly classified as low to intermediate. The mineralogy of representative samples are mostly quartz, plagioclase with intermediate to small amounts of clay minerals including some that exhibit swelling i.e. smectite. The high sand and low clay content caused low slope stability due to the low water retention in soil, low plasticity, and low shear strength of materials while the resulting porosity led to poor drainage. The results suggest that the physical characteristics of the soil play a role in the occurrence of landslides in Benguet, wherein most rock units have been affected by alteration that resulted in changes in the geotechnical properties of the soil.
Evaluation of Heavy Rainfall Data Generated By Typhoons in The Philippines with Near-Real-Time Satellite Rainfall Products

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Heavy rainfall generated by typhoons is challenging to quantify with rain gauge measurement because it has an uneven distribution in remote areas. Satellite rainfall products (SRPs) provide integrated spatial coverage of rainfall estimations, even for remote areas. The current study performed 3-hourly evaluations of near-real-time SRPs (i.e., the Integrated Multi-satellitE Retrievals for Global Precipitation Measurement [IMERG], Global Satellite Mapping of Precipitation [GSMaP], and Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks [PERSIANN]) during five typhoon-related heavy rainfall events in the Philippines between 2016 and 2018. The aforementioned evaluations were performed through a point-to-grid comparison by using various statistical evaluation criteria and graphical methods for the 34-knot wind radius of the typhoons, rainfall intensity, terrain, and wind velocity effects. The results revealed that the IMERG exhibited good agreement with rain gauge measurements and exhibited high performance in detecting rainfall during five typhoon events. The GSMaP dataset exhibited an overestimate with the rain gauge measurement during peak rainfall. All the SRPs tended to overestimate rainfall during light to moderate rainfall events and underestimate rainfall during heavy to extreme events. The IMERG exhibited a strong ability to detect moderate rainfall events, whereas the GSMaP exhibited superior performance in detecting heavy to extreme rainfall events. The GSMaP exhibited the best performance for detecting heavy rainfall at high elevations, whereas the IMERG exhibited the best performance for rainfall detection at low elevations. The IMERG dataset has a better capability to identify heavy rainfall under diverse wind speeds. The GSMaP dataset is more capable of identifying heavy rainfall events based on wind velocity in the eastern and western parts of the mountains over Luzon Island. The current study demonstrated that the IMERG and GSMaP datasets exhibit promising performance in detecting heavy precipitation caused by typhoon events.
Monsoonal variation of Raindrop Size Distribution (DSD) in Metro Manila, Philippines

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The study evaluates the seasonal characteristics of the Raindrop size distribution (RSD) during the southwest monsoon, northeast monsoon, and transition period in Metro Manila. The two-year worth of rainfall measurements of the 2nd-generation PARSIVEL Disdrometer (PARSIVEL2) collected at the Science Garden station, Quezon City (14.6° N, 121.04°E) were used to investigate the microphysics of monsoon precipitation. The RSD observations are grouped according to the onset and termination dates of the monsoon periods. Results show that small raindrops dominate the NEM rainfall while large raindrops are observed more during the pre-SWM and SWM periods. The high values of intercept (Log10 Nw), slope (Λ), and shape (µ) parameters observed during the NEM period signify the high concentration of small raindrops, while the high values of mass-weighted mean diameter (Dm) during the pre-SWM and SWM periods indicate larger raindrops. Moreover, convective precipitation during the monsoon periods in Metro Manila is found to exhibit RSD characteristics that are in between those in the maritime and continental regions. Finally, the reflectivity-rain rate (Z-R) relations of the monsoon seasons are found to deviate from the conventional Marshall-Palmer Z-R relation and have important implications in radar operations. The findings show that the seasonal variability of RSD has relative importance in the further development of quantitative precipitation estimation (QPE) in weather radars and the parameterization of microphysics schemes in numerical weather prediction models.
Analyzing tropical cyclone structure with a deep learning model utilizing satellite imagery

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Tropical cyclone (TC) structure analysis is crucial for TC research and disaster prevention. However, observational limitations can make it difficult to accurately analyze TC structure. To address this issue, we developed a deep learning model using the convolutional neural network (CNN). This model uses satellite observations to estimate TC structure and provides objective, globally consistent results. Our model is expected to improve the temporal and spatial resolution of typhoon structure observations, making it a valuable tool for TC research and disaster prevention.

To train the CNN, label data is required to compute the loss function during the training process. In this study, the structural parameters of the best track data and a physically-based parametric wind model were used to estimate the axisymmetric wind speed structure of TCs. However, the wind profiles are not accurate enough, so we used ERA5 reanalysis data to correct the maximum wind and wind field at outer radii. The model was trained on data from 2004 to 2016 and showed good performance. The intensity RMSE and 9.9 kt and storm wind radius MAE of 43.6 km. Independent verification of the 2017-2018 TCs using ASCAT and SAR sea surface wind observations showed the model's ability to reasonably estimate TC structure. The results showed that TCs with weaker intensity had larger estimation errors in wind speed, which may have been due to the looser structure in the satellite images. Landfall TCs had even larger intensity errors. Additionally, the estimation errors were related to the spatial distribution of the dataset.

Using the objective method of this study, the reanalysis data of tropical cyclone (TC) structure from 1981 to 2020 was reconstructed through satellite images. We also attempted to convert the one-dimensional axisymmetric wind speed profile into a two-dimensional wind field and compare it with actual observations. The results showed that the method can generally estimate the asymmetric wind speed structure of TCs, and further research is ongoing.

Key words: TC structure, CNN, satellite observations
**Impact of assimilating radar data on forecasting enhanced southwest monsoon rainfall over the Philippines**

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Last July 2021, the Philippines was affected by the southwest monsoon enhanced by Typhoon In-fa, bringing heavy rainfall over the western sections of the country. This study investigates the impact of convective-scale assimilation of radar reflectivity and radial wind data using the three-dimensional variational data assimilation (3DVAR) system of the Weather Research and Forecasting (WRF) model in forecasting the heavy rainfall brought by the enhanced southwest monsoon. In addition, two different methods of assimilating reflectivity data are explored: indirect and direct reflectivity assimilation. The assimilation of reflectivity data added moisture to the analysis field, resulting in lower bias verified against satellite-derived rainfall estimates during the first forecast hours compared with the control run. However, assimilating only radial wind data did not have significant impacts on rainfall forecasts compared to the control run. The experiments show that assimilating radar data improved the spatial accuracy of forecast rainfall, with the reflectivity assimilation having better fractions skill scores (FSS) of hourly rainfall accumulations compared with the control run. The results of this study demonstrates the potential positive impacts of assimilating radar data in forecasting rainfall during enhanced southwest monsoon events over the Philippines.
Development of Z-R relationship for Subic Radar Station using the traditional matching method

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The emergence of weather radars has become powerful to analyze the microphysical structure of the storms including precipitation estimation critical to deliver early warning information and alerts to vulnerable communities. However, weather radar does not measure precipitation directly. Therefore, Radar reflectivity (Z) to Rain rate (R) conversion using the empirical power-law in the form of a Z-R relationship (Z = a·R^b) provides rainfall measurements estimate. A new Z-R Relationship is sought to be introduced and adopted which will be suitable for the radar stations in the Philippines. The reflectivity data used between June and December 2018 at the Subic radar, paired with the five (5) rain gauges within the fifty (50) km radius of the Subic radar of the same periods were used. A Z-R relationship in the form Z=409.78R^{1.21} shows acceptable statistical indicators, making it suitable for radar rainfall prediction for Subic radar in the Philippines.
Impact study of updating SST on tropical cyclone predictions in the western North Pacific

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The ocean surface plays a major role in modulating the TC intensity and structure changes. It is well known that strong winds of a TC can induce significant upwelling in the ocean, bring down the underneath SST and affect subsequent TC intensity for slow-moving storms. Without coupling of ocean model, the intensity prediction skill of atmospheric-only TC models suffers from this shortcoming. However, due to computational limitation, most operational TC prediction models are not coupled. The TC prediction system, TWRF of Central Weather Bureau uses the forecast fields from the NCEP FV3 for the boundary conditions. Due to the lack of ocean-coupling, TWRF suffers over-prediction of TC intensity when a storm moves slowly over the ocean. A new strategy is designed for this remedy that uses the predicted SST from ECMWF coupled IFS instead of a fixed SST from NCEP forecast fields. Typhoon In-Fa is selected due to its over-intensified prediction and slow speed. In the operation run where the SST is fixed, the over forecast intensity error is 35 hPa in the 3km domain at 120h. When the SST is updated with ECMWF predicted SST, the intensity errors are improved by 20 hPa. Meanwhile, the track error has increased slightly in the 3km domain. We speculate that the slight degradation is due the inconsistent between the bottom boundary condition from the ECMWF and the lateral boundary condition from NCEP. We tested a combination strategy using NCEP and EC, and a blending of them as the boundary conditions for TWRF. The blending strategy, mixing the EC and NCEP forecast fields as the lateral boundary condition and ECMWF SST as the bottom boundary condition, performs the best in the test case of In-Fa. The blending strategy consistently beats the operation version of TWRF on the intensity prediction with 77 cases/7 typhoons. This blending method posts as a working strategy for uncoupled models to account for the feedback from the ocean in a computationally efficient way.
Characteristics of Deep Convective Clouds, Precipitation, and Cloud Properties of Rapidly Intensifying Tropical Cyclones in the Western North Pacific

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Toward the understanding of rapid intensification (RI) of tropical cyclones (TCs) in the western North Pacific, the TC’s deep convective cloud (DCC), precipitation, and cloud properties in terms of cloud effective radius, optical thickness, and top height from satellite observations are investigated. Mean and radial distributions of the variables at different intensity stages and intensification categories are examined. The relationship indicates that the DCC percentage and temperature, especially their radial distributions, could be used to identify an impending RI regardless of TC intensity. Meanwhile, the mean and radial distribution of precipitation may discriminate RI from non-RI in tropical depression (TD) and tropical storm (TS). The radial distribution of the cloud properties in rapidly intensifying TD and TS also suggest that most of the clouds near the center of the storm has deepened already while those that are far from the center are generally in developing or dissipating stage. Moreover, rapidly intensifying TCs, regardless of their intensities, manifest common DCC, precipitation, and cloud properties characteristics near the TC center. It is to be noted that the different mean and radial distribution characteristics of the variables between initial and continuing stages of RI are inferred to be artifacts of their intensities and RI rates (or radius of maximum wind sizes) rather than whether the TCs are at the onset or 24 hr of RI.
Application of WRF FDDA to initialize typhoon structure in Typhoon WRF (TWRF) prediction by utilizing predicted typhoon wind field

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TWRF model based on the Advanced Research Weather Research and Forecasting Model (WRF-ARW) is the operational tropical cyclone (TC) prediction system at the Central Weather Bureau (CWB). The forecast performances of track and intensity in 2016~2020 were found competitive with that of two leading global models, EC and NCEP (Hsiao et al. 2020). The average error of initial TC intensity and position are about -7 hPa and 37 km respectively in 2016~2021. This study focuses on solving the initial TC intensity and position biases. Reasonable initial TC structure could not only reduce model spin-up time, but also improve the performance of TC forecast.

WRF Four-Dimensional Data Assimilation (FDDA) is a data assimilation method that continuously assimilates observations into the mesoscale models through a nudging/Newtonian relaxation approach and forces the model state toward the observational state by adding artificial error correction terms to model equations (Liu et al. 2008a; 2008b; Pan et al. 2015). Its benefits are easily to be operated and requiring less CPU. This study adopted FDDA in TWRF model to assimilate the forecast TC structure. The target observation winds were predicted 1~15 h with radius less than 100 km from TC center as TC inner core structure, and its initial time was 12 h before major TWRF run. We assimilated hourly target observation winds into FDDA objective analyses and apply it to TWRF with partial cycle assimilation.

The period when Typhoon Chanthu (2020) was closed to Taiwan was selected to examine the impact of FDDA with forecast wind compared with observation wind. The results pointed out that adopt FDDA with the forecast TC inner core winds not only improved the representativeness of the initial TC location and intensity, but also advanced the prediction on the typhoon track and intensity of TWRF. The improvements were comparable with the result of nudging observation wind. Other 9 TC cases over the ocean were then examined to robust this initialization method. The results showed great initial TC location improvements. The detail discussion will be presented in the conference.

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Given that large-scale environmental conditions are insufficient to explain the variability of the intensification of tropical cyclones (TCs), investigating storm-scale internal dynamical mechanisms that are related to precipitation, convection, latent heating, and wind structure is of crucial importance. In this study, the selected internal dynamics of super typhoon Goni (2020), one of the most intense TCs on record, were investigated using gridded model, satellite, and TC track data. By examining the radial distributions of the variables in terms of both TC intensity and intensification, it was found that Goni, as an intensifying tropical depression (TD), had relatively colder and more abundant deep convective clouds (DCC) that were associated with heavy precipitation. In the major TC stage, DCC of colder temperatures had become more abundant within 3-6 radius of maximum wind (RMW) which corresponds to the warm-core effect. The study indicated that Goni’s intensity was sustained likely due to the efficient latent heating produced by the deposition and condensation processes at the middle and upper tropospheric levels. Additionally, heating at the boundary layer during the early, non-intensifying stages may have encouraged subsequent intensification. Lastly, Goni’s monotonous fullness ratio during its early stages led to its ideal wind structure that exhibited its extreme rapid intensification. Findings in this study can be used to determine the governing internal dynamics that control the intensification of a TC.
Citizen Science for Landslide Early Warning System: 
The Project LIGTAS Philippines Initiative

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The Philippines has always been subject to extreme weather phenomena, and rainfall-induced landslides are the most common slope failure events in the country where one of the most significant number of landslides coincidental to typhoons and heavy rainfall have been recorded. These events have caused considerable damage, destruction of property, and loss of lives. The ability to develop an early warning system that will inform the people of possible slope failures is an integral component to Project LIGTAS.

Project LIGTAS is a research initiative which develops and early warning system for rainfall-induced landslides and community participation in the Philippines. A website (ligtas.uplb.edu.ph) was developed to allow the community to report landslide events and access landslide information and advisories.

Landslide reporting can be done through mobile and in the portal. Reports from the community, as well as fieldwork, and secondary data are stored in the database which will be used for threshold development specific for the region. These developed rainfall-induced threshold for landslide is vital in the early warning system which will serve as a decision-support tool of the local government units for disaster risk management.

Keywords: Citizen science, landslide, Project LIGTAS
Soil Characterization of Landslide Areas in Volcanic Regions of the Philippines

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Aside from the risks from volcanic eruptions, the susceptibility of volcanic regions to landslides continues to be an additional challenge. Brought about by intense rainfall events, an increase in water content and pressure within the soil body often leads to shallow landslide occurrences in the country. However, water movement during landslide events varies significantly with different types of soil, hence, the importance of taking soil properties into account in studying landslide mechanisms. The study aims to characterize the physical properties of soils from landslide areas of Laguna and Batangas provinces of CALABARZON and Albay and Sorsogon provinces of the Bicol Region, all of which are volcanic in nature.

Soil analyses, such as moisture content (gravimetric method), soil texture (hydrometer method), particle density (pycnometer method), bulk density, %porosity, Atterberg Limit tests, and hydraulic conductivity (Falling Head Permeability test) were carried out. Higher sand percentages were observed from the soils of CALABARZON, while higher clay percentages were exhibited by the soils from the Bicol region. Following these grain-size compositions, soils of the CALABARZON region have mostly low to very high plasticity, while soils from the Bicol region have intermediate to extremely high plasticity. Varying porosity and density values are computed from soils of the CALABARZON region, while similar relatively high values were derived from soils of the Bicol region. Initial test on hydraulic conductivity revealed low permeability of fine-grained soils from the Bicol region. From these findings, slope failures in the CALABARZON region can be more easily triggered with lower precipitations than landslides in the Bicol region, which require a higher amount of water before slope failure.
Are we there yet? The case of deriving rainfall-landslide thresholds for shallow landslides in the mineralized and volcanic regions of the Philippines

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The archipelagic Philippines is located at the gateway of extreme weather events, thus, making it susceptible to various kinds of geomorphologic and hydro-meteorologic hazards. Among the numerous disasters caused by extreme events, landslides are regularly occurrences with devastating impacts to properties and lives. In an area vulnerable to such damages, intensive researches are needed to prepare communities better. Such work requires extensive data, in both space and time. The national government has identified the need to mitigate landslides and its effects through initiatives such as Project LIGTAS or Landslide Investigations on Geohazards for Timely Advisories in the Philippines. Project LIGTAS focuses on the generation of a non-structural preventive approach to mitigate landslide disasters using rainfall-landslide thresholds. This study aims to present the improved thresholds for the provinces of Benguet and those in the Southern Tagalog region. This paper discusses the encountered challenges in data acquisition and the solutions employed by the team. Ways forward to operationalize a localized landslide early warning system within the study areas are also presented.

With the current data, results show that 27mm of rainfall already starts to trigger slope failures in the Southern Tagalog region, while landslides in the selected areas in the Bicol region are triggered at around 90mm of rainfall. Lower thresholds were generated for the Benguet province wherein slope failures start at 12mm of rainfall. In a data-scarce country, landslide events data were collected from various platforms and through different methods while rainfall data used in this study were provided by the Department of Science and Technology-Philippine Atmospheric, Geophysical and Astronomical Services Administration (DOST-PAGASA) and Advanced Science and Technology Institute (ASTI) but for cases where rain gauges are non-operational, satellite data was used. The results of this work were then used in the developed landslide warning system posted on the LIGTAS website (www.ligtas.uplb.edu.ph) and a public advisory patterned to the template of the Department of Environment and Natural Resources - Mines and Geosciences Bureau (DENR-MGB). Additionally, the simplicity of the method provides a higher chance of adaptation by other regions in the country.

Keywords: Landslides, Data mining, RL thresholds, Project LIGTAS
Non-analog future climates and the outlook for rainfall-induced landslides in the Philippines

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It is expected that towards the end of the 21st century, global climates would change by factorial combinations that are so much unlike the present and will do so in an accelerated manner. The continued rise in air temperatures will persist to affect global water balance and lead to non-analog climate extremes. Exceptionally wet weather systems have been occurring more frequently than usual. Downscaled global models predict that the Philippines and its surrounding regions will experience intensified tropical cyclones with higher rainfall rates. The frequency of cyclones will not change much. More worrisome is the predicted increase in the number of extreme precipitation events.

To provide an idea on how future slope failure statistics may change, we use current rainfall-landslide thresholds derived for the following Philippine regions: 1) the volcanic Bicol Peninsula along the eastern seaboard, 2) the volcanic Southern Tagalog Region (CALABARZON) to the northwest of Bicol, and 3) the northern Benguet province, typified by higher elevations and mineralized terranes, and integrate them with regionally downscaled climate change projections (medium and high emission scenarios) developed by the Philippine weather bureau.

Projections for very wet days (P95), both for the medium and high emission scenarios, indicate decreases in the number of landslide events for most periods. Landslides are only projected to increase during the later years for the medium emission scenario, and mostly only for the northern Benguet province (4.9% increase). We suggest that this reflects a compensation for the longer dry conditions (droughts) predicted for the same periods for most regions across the country. Additionally, it is also possible that threshold levels would already have shifted to higher values due to slope stabilization effected by more frequent extreme rainfall events that would have, over time, slowly washed away instability on slopes. In contrast, projections for the very extremely wet days (P99) show marked increases in slope failures especially for the later periods for both medium and high emission scenarios. This indicates that during such extreme non-analog events, the usual biophysical controls to slope failures would not hold sway to the more effective impacts of extreme precipitation.
POSTER PRESENTATIONS:
Meteorology
Radar Analysis of Landfalling Typhoons

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Recent studies of landfalling typhoons observed by Taiwan weather radar network will be presented. A history of radar analysis algorithm development related to typhoon study will be briefly reviewed. Terrain effect on landfalling typhoons' intensity and precipitation changes are especially emphasized. Studies include (1) the effect of coastal barrier jet (CBJ) on the intensity and track changes of landfalling typhoons; (2) Bulk microphysical properties of near-center secondary rainbands of landfalling typhoon (Soudelor 2015); and (3) Leeside meso-low and localized strong winds of typhoon near landfall (Meranti 2016).
Seasonal variability of carbon and nitrogen transfer efficiency between specific plankton size groups in a subtropical deep oligotrophic freshwater ecosystem

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Trophic transfer efficiency (TTE) of carbon and nitrogen, which are essential elements in understanding ecological processes involving material flows and predator-prey relationships, exhibited a higher but highly variable efficiency rate in oligotrophic freshwater lakes as opposed to eutrophic lakes. It is unclear how abiotic factors influence the TTE of carbon and nitrogen in the link between specific plankton size groups in oligotrophic freshwater ecosystems. To fill this gap, based on the in situ investigation in Fei-Tsui Reservoir, a subtropical deep oligotrophic freshwater ecosystem, the seasonal variability of TTE in specific plankton size groups were comprehensively studied from July 2014 to November 2020. The plankton size relationship was analyzed by comparing the δ13C and δ15N as well as isotopic identification (ID) of each specific plankton size group during the summer and the winter. The influence of environmental factors on the TTE of carbon and nitrogen were examined. Our results revealed the tight trophic link of the smallest plankton and large microzooplankton in two contrasting seasons, and the TTE between the trophic levels were significantly different between the summer and the winter, which indicates that material flows between the trophic levels were variable. Simple linear regression analyses showed that increasing 0-90 m depth-averaged concentrations of NO2— and NO3— influenced the seasonal variability of TTE of carbon and nitrogen between trophic levels, indicating the importance of nutrient enrichment in the material flows in the aquatic food chain in oligotrophic freshwater. Multivariate analyses revealed that increased carbon transfer was influenced by the combined effects of water temperature and nutrient supply and that increased nitrogen transfer was associated with nutrient supply, suggesting that carbon flow may be linked to both effect of temperature-dependent metabolic activity and nutrient supply, and that nitrogen flow was primarily influenced by nutrient supply. Our findings indicated that the variability of TTE in oligotrophic lakes is controlled by the environmental changes, primarily variability of nutrient concentrations. Such information about the seasonal variability of TTE and how abiotic factors affect the efficiency rate of material transfer between trophic link of specific plankton size can be helpful for managing aging lakes and reservoirs.

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While the importance of internal dynamical processes in the variability of intensification has been highlighted in recent years, environmental conditions must also be investigated because they set the stage for a tropical cyclone (TC) to intensify. This study utilized gridded model data and TC track data, to characterize various environmental conditions of super typhoon Goni (2020). By evaluating the radial distributions of the variables, it was found that warm (> 29 °C) and anomalous (> 0.7 °C) sea surface temperature persisted throughout the evolution of Goni, with the warmest and most anomalous waters observed during Goni’s formation near its center. High moisture content (> 70%) was also found at both the low and mid tropospheric levels at the vicinity of Goni. A dry air intrusion was observed during the late stages which may have contributed to the weakening of Goni. Moreover, the computed deep and low-level vertical wind shears (VWSs) were both favorable for Goni’s intensification. In the weakening category, the low level VWS was found to be more detrimental to Goni’s intensification. Furthermore, relative vorticity within the TC center had a positively strong correlation with TC intensity, whereas the advection of relative vorticity correlated well with TC intensification. Lastly, efficient outflow was generally observed while the presence of an inflow layer in the lower stratosphere may have induced an upper-level warm core, which most likely encouraged further intensification of Goni during the late stages. Findings in this study can be used to identify crucial environmental conditions that may lead to further intensification of a TC.

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The Philippines is hit by 9 typhoons on average each year, which is about three times as many as Taiwan. Many of the typhoons bring heavy rainfall to various regions of the nation, and post great disaster risks to the people. Therefore, for the Philippines, it is very important and necessary to have reliable techniques to forecast heavy rainfall from typhoons, and to issue warnings in advance for disastrous weather. Research on the time-lagged ensemble forecasts of the Cloud-Resolving Storm Simulator (CReSS) in the past has mostly selected typhoons with considerable intensity as target cases. But the harmfulness of weaker typhoons should not be ignored. For example, Typhoon Megi that hit the Philippines in April 2022 was weak in intensity, but it brought heavy rainfall that caused serious casualties and huge financial losses in the Central Philippines.

Typhoon Megi (2022) has the characteristics of weak intensity, slow movement, and staying in a complex environment. These aspects are different from most of the cases that have been studied in the past. Therefore, this study aims to evaluate the forecast skill of the CReSS model using the high-resolution time-lagged ensemble strategy for the track, intensity, and quantitative precipitation forecasts (QPFs) of Typhoon Megi (2022). This study will compare the model's forecast results with the best track data of the typhoon, satellite observations, and rain-gauge data. It will also use the forecast probability and forecast skill scores for specific rainfall thresholds to measure the reference value of the model's QPFs. It is hoped that the research results can not only improve the evaluation of the time-lagged ensemble forecasts to facilitate disaster prevention and response, but be consulted for subsequent applications and research.

Keywords: Philippines; Typhoon Megi (2022); Cloud-Resolving Storm Simulator (CReSS); time-lagged ensemble forecast; skill score.
Weather and Climate analysis of Tropical cyclone genesis clustering events in Western North Pacific Extended-Weather Analysis

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In the boreal warm season (May-September), tropical cyclone genesis (TCG) is active in the West North Pacific (WNP) region. TCG occurs in WNP monsoon trough that are influenced by active weather and climate oscillations, and Rossby wave energy dispersion of a preexisting mature TC. In addition, TCG tends to cluster in a short period and absent at other times. In this study, we investigate the weather (or extended weather) disturbances responsible for the extreme TCG clustering and how the weather disturbances are influenced by low-frequency climate oscillations including QBWO, ISO, and ENSO.

We first calculate the maximum number of TCG per 10 days in each JJASO season from 1990 to 2019 to determine the most extreme TCG cases. Four cases with 5 TCGs in 10-days are selected. By analyzing the extended weather disturbances of the four periods, we find that 15 out of 20 TCs occurred in positive vorticity phase of QBWO and 4 TCs formed following a preexisting mature TC suggesting Rossby wave energy dispersion within positive vorticity region of QBWO. A further analysis of the climate conditions shows that, three of the four extreme TCG-clustering events occurred in late July-August during La Niña developing summer with inactive BSISO, while the other occurred in El Niño developing July with active BSISO in WNP.
**2020/21 East Asian Winter Monsoon Sub Seasonal Contrast and the Influence on the Temperature over Northern South China Sea Region**

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East Asian Winter Monsoon is characterized by cold and strong Siberia-Mongolia High. 2020/21 East Asian Winter Monsoon was notable for its earlier start in November and strong sub seasonal contrast in which the Siberia-Mongolia High was abnormally cold and strong before mid-January but was abnormally warm and weak after mid-January. Before mid-January, there were three strong Siberia-Mongolia High intensification events, but only the third intensification event which started from 27 December 2020 to 11 January 2021 had caused three cold events over Hongkong and Taipei. The first two cold event occurred over Hongkong and Taipei on 31 December 2020 and 8 January 2021. The third cold event occurred over Hongkong and Taipei on 11 and 12 January 2021, respectively. The Siberia-Mongolia High from the three cold events were originated from Artic Ocean, Ural Mountain, and Tibetan slope and they moved toward the South China. After mid-January, there were two weak Siberia-Mongolia High intensification events, but only the second intensification event which started from 6 February to 18 February 2021 had caused one cold event over Taipei and Manila on 18 and 19 February respectively. The Siberia-Mongolia High from the cold event was originated from the Mongolian Plain and it moved toward the East China Sea.
Raindrop Size Distribution (DSD) characteristics during the Southwest Monsoon period over Western Luzon, Philippines

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The Raindrop size distribution (RSD) characteristics over western Luzon during the Southwest Monsoon (SWM) periods from 2020 to 2022 are examined using a network of OTT PARSIVEL2 Disdrometer. The three-year worth of RSD observations was collected from four Disdrometer stations, namely: Science Garden, Quezon City (SG, 14.6° N, 121.04° E), La Mesa, Quezon City (LM, 14.7° N, 121.07° E), Clark, Pampanga (CK, 15.18° N, 120.5° E), and Malolos, Bulacan (MS, 14.8° N, 120.8° E). Results show significant RSD differences between MS and CK stations. On average, the RSD over MS station is dominated by a high concentration of relatively smaller raindrops, while large raindrops are more prevalent over CK station. On the other hand, similar RSD properties and integral rainfall parameter (IRP) values were observed over SG and LM. In all the stations, values of mass-weighted mean diameter (Dm) and normalized intercept parameter (Log10 Nw) are higher in convective than stratiform rainfall. However, convective rainfall over the CK station has the highest mass-weighted mean diameter (Dm) during the SWM period. The diurnal variation of RSD also showed higher Dm over CK station, especially in the late afternoon to early evening hours. Radar reflectivity – rain rate (Z-R) relations derived from the RSDs at each station showed a clear difference between stratiform and convective rainfall. The Z-R relations obtained from each station are found to be different from the conventional Marshall & Palmer relation but similar to Rosenfeld’s tropical relation. The shape-slope (µ-A) relations derived from the gamma RSD are also shown to be distinct at each location. Despite being influenced by a similar synoptic system during the SWM period, the geographical setting of the stations and orography may be the primary reasons for the observed RSD differences.
ORAL PRESENTATIONS:
Solid Earth
The motion of the Philippine Fault and its tectonic significance

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The Philippine Fault roughly bisects the Philippine mobile belt. To the west, the Sunda Plate subducts eastward along the Manila Trench, while to the east the Philippine Sea Plate subducts westward along the Philippine Trench. To the north of the Luzon Island, the Philippine Sea Plate has clockwise rotated and converged northwestward relative to the Eurasian Plate with a pole of rotation located to the northeast of Japan. In contrast, the Philippine mobile belt has rotated anti-clockwise relative to the Sunda Plate. In consequence, there is an ambiguous zone of plate motion between the south Taiwan and Luzon islands. It was believed that the portion of the Philippine Fault in Luzon Island is in western Luzon roughly north-south trending. However, it is noted that from south to north the Philippine Fault has changed its orientation from ca. NW-SE to ca. N-S near 121° E and 16° N.

To understand the actual configuration of the Philippine Fault, we have conducted a marine geophysical survey off western Luzon in March-April 2022. Our results show that Philippine Fault in northern Luzon has extended northwestward to the offshore and ends at the Manila Trench. It suggests that the main trajectory of the Philippine Fault should be along a small circle of the plate convergence between the Philippine mobile belt and the Sunda Plate whose rotation pole is located just to the south of the Palawan Island. To the north of the main Philippine Fault trajectory, the plate motion is mainly dominated by the plate convergence between the Philippine Sea Plate and the Eurasian Plate. As a result, several faults in the Luzon Island and its western offshore area could be considered as a horse-tail structure of the northernmost Philippine Fault. Because of the Philippine Sea Plate/Eurasia Plate convergence, a positive flower structure has occurred in the western Luzon and its offshore, including the uplift of the Vigan High off western Luzon. The Manila Trench has been segmented by the northern end of the left-lateral Philippine Fault near 119° 15’E and 17° 30’N. To the north of the separation point the Manila Trench is trending NE-SW, while to the south the Manila Trench is trending almost N-S.
Geomorphology and Structure of the East Solsona Basin Fault (West Ilocos Fault System) in Northern Luzon, Philippines

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The West Ilocos Fault System (WIFS) is described to be the northern extension of the 1200-km-long Philippine Fault Zone and consists of a network of strike-slip, reverse, and normal fault segments. The two major active faults of the WIFS are 1) the NNE-trending Vigan–Aggao Fault which transects the western section of Ilocos Norte and Ilocos Sur and, 2) the NNW-trending Abra River Fault which traverses the Cordillera Central. Oblique sinistral movement of these two faults is reported to have formed and developed the 15-km-wide Solsona Basin, where active strands of the WIFS were delineated in its eastern section. Despite its active seismotectonic history, there is limited information on the seismic hazard potential of the WIFS. In this study, we conducted geomorphological analysis, ground penetrating radar (GPR) surveys, and paleoseismic trenching to examine the characteristics of the understudied eastern strand of the WIFS, herein referred to as the East Solsona Basin Fault (ESBF).

The gently sloping scarp (striking N20-35°E and dipping NW) of the ESBF is observed in the municipality of Marcos in Ilocos Norte. Morphotectonic features such as offset streams, truncated spurs, and elevation changes were interpreted from anaglyph images and red relief image maps (RRIM) derived from aerial photos and LiDAR DEM, respectively. Geomorphic markers show a general sinistral movement of the fault with a dip-slip component. Ground penetrating radar surveys conducted along and across the fault scarp reveal discontinuous reflectors, corresponding to minor faults at a depth of about 5 m. A paleoseismic trench was then dug across the fault scarp in Brgy. Cacafean, exposing the main fault, its splays, and displaced stratigraphic units. Trench walls reveal eight to eleven sediment units and channel deposits which were delineated and described based on color, thickness, and sedimentological characteristics (e.g., texture, sorting, composition). Sediments are poorly consolidated and generally consist of muddy to silty sand, silty clay, and sandy gravels with angular to sub-rounded pebble- to cobble-sized clasts of igneous rocks sourced from the Ilocos Foothills. At least two faulting events that show normal displacement of stratigraphic horizons were interpreted based on paleo-earthquake indicators such as a) upward termination of the fault, b) thickening of deposits on the downthrown side of the fault, and c) downward increase in displacement. Transtensional movement of the ESBF is inferred based on its morphotectonic features and subsurface structure as revealed from paleoseismic trenching. The timing and recurrence of these faulting events will be constrained as radiocarbon ages become available.
Oblique blind thrust fault in northern Luzon illuminated by the 2022 Mw 7.0 Abra earthquake and implications for regional seismic hazards

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On 27 July 2022, the Mw 7.0 Luzon earthquake struck northwestern Luzon. This is the largest seismic event to have occurred along the Philippine Fault Zone in northern Luzon since the 1990 Mw 7.7 Luzon earthquake. The mainshock is characterized by an oblique thrusting with a shallow focal depth of 10-27 km and is followed by thousands of aftershocks in a week. The absence of surface rupture accompanying the earthquake raises the question that what seismogenic structure was responsible for this event. To investigate the coseismic slip during the 2022 Luzon earthquake, we exploit the coseismic surface displacements constrained by radar satellite imagery and GNSS measurements. We generated a coseismic interferogram using the synthetic aperture radar (SAR) images from Copernicus Sentinel-1A descending track 32 on 21 July and 2 August 2022. In addition, nine GNSS measurements after the mainshock are included to constrain the three-dimensional coseismic displacements. We rely on a kinematic inversion combining InSAR and GNSS data to explore the fault geometry and the corresponding slip distribution. The best fault geometry resulting from the uniform slip model exhibits a strike of N353° and a dip of 29° to the east. A uniform slip of 1.2 m along a rake of 33° takes up a 41-km by 22-km surface area at depths ranging from ~12 to ~22 km. The inferred fault geometry apparently deviates from the 90°-dipping Abra River fault, the closest active fault to the mainshock. Instead, the up-dip surface projection of the fault roughly coincides with the southern segment of the Vigan-Aggao fault, which represents the active deformation front onshore along northwestern Luzon. The southward propagation of coseismic slip and aftershocks terminated at a distance of 50 km from the northern end of the 1990 Luzon earthquake rupture, leaving a seismicity gap in between. Coulomb stress changes of up to 2 bars are imparted at the shallow portions of the Vigan-Aggao and Abra River faults, where the updated 100-year seismic potential reaches Mw 7.0-7.7, given the unusually thick seismogenic layer of ~30 km in northern Luzon.
Hualien Ridge: a tectonical ridge transitioning from plate collision to subduction

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Located in eastern Taiwan, the Longitudinal Valley is generally considered as the collisional suture between the Philippine Sea and the Eurasian plates. To the northeast, the Philippine Sea Plate is subducting beneath the Ryukyu Arc. The corner between the eastern Taiwan and the Ryukyu Arc system is the transition from plate collision to plate subduction. In consequence, the tectonics is complicated and the earthquakes are rather frequent. In this study, we use marine geophysical data to study the submarine Hualien Ridge that is situated in this plate collision/subduction transition. Our results show that the Hualien Ridge can be tectonically divided into the active southern Hualien Ridge and the inactive northern Hualien Ridge. Several active faults trending ~N30°E exist in the southern Hualien Ridge; some faults could be linked to the active faults in the Milun Tableland. The structures in the southern Hualien Ridge and the Milun Tableland display a pop-up structure that is subject to the oblique compression from the northwestward collision of the Philippine Sea plate. Moreover, the ~N30°E trending structural faults are the results of the transpressional fault system. However, the Milun Fault, the western boundary of the fault system, probably terminates near 24°04’N, where a pronounced bathymetric structure trending N300° exists. On the other hand, in the northern Hualien Ridge we can only observe several blind normal faults covered by ~100 m thick sediments. Overall, The distinct variation of tectonic activity in the Hualien Ridge underlines the transition from the actively plate collision to inactively collision or partially subduction of the Philippine Sea Plate relative to the Eurasian Plate.
Advances, challenges, and future directions for expanding the use of satellite radar interferometry for Philippine tectonics: case studies from Leyte and Mindanao, Philippines

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Interferometric synthetic aperture radar (InSAR) has played a key role in advancing our understanding of ground deformation sources thanks to its ability to acquire data for wide areas regardless of cloud cover. Further, an increasing number of SAR missions and easier access to data over the past decade has allowed quick response efforts to map and identify earthquake ruptures for disaster response. In this talk, I will present findings on ground deformation sources and fault mechanics in the Philippines from satellite InSAR observations. With time-series analysis and slip modeling from ALOS InSAR data (mission spanning 2007-2011) and coseismic interferograms from ALOS-2 and Sentinel-1, we constrain the distribution of interseismic creep and the location of a 20-km long locked segment on a 100-km long section of the Philippine Fault on Leyte island. In Hinunangan (southern Leyte), ALOS data also reveal the source of a magnitude 5.3 earthquake in July 2007 to be a previously unmapped shallow right-lateral fault perpendicular to the Philippine Fault. Further, the ground deformation map of Leyte shows subsidence of ~2.5 cm/yr related to geothermal energy production as well as possible post-main event mass movement in the 2006 Guinsaugon landslide footprint. In Mindanao, InSAR data from more recent missions of ALOS-2 and Sentinel-1 covering the 2017 magnitude 6.0 Lanao del Sur earthquake and 2019 Cotabato-Davao earthquake sequence reveal the location of blind and surface-rupturing faults ahead of field work. Observations for these different cases involve some challenges imposed by activity in the troposphere and ionosphere that obscure ground deformation signals. The developments in satellite radar interferometry highlight the value of expanding the use of InSAR for societal and scientific advancement, as well as exploring avenues for improved observation techniques.
Exhumation of high-pressure metamorphic rocks in the Yuli belt, eastern Taiwan

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Eastern Taiwan is an ideal natural laboratory to study orogenic evolution involving subduction, accretion, collision, exhumation, and uplift. In particular, the Yuli belt in eastern Central Range is the only geologic unit that contains high-pressure (HP) metamorphic rocks and bears key information for deciphering the geodynamic history of the Taiwan orogen. One outstanding question about HP metamorphic rocks worldwide is how they were exhumed back to the surface. Several hypotheses or theoretical models had been formulated over the past three decades, but a global consensus has not been reached yet. This presentation speculates on the exhumation of Taiwan’s HP rocks according to recent petrological findings. The HP meta-igneous or meta-volcaniclastic rocks (e.g. garnet-paragonite-epidote amphibolite, glaucophane schist) and adjacent garnet-bearing pelitic schists are exclusively associated with antigorite serpentinites. Peak metamorphic conditions of these multiple rock types collectively attest HP metamorphism at a warm subduction zone. Given the great diversity in protolith, the rock associations are meta-melanges and likely represent exhumed masses from a slab-mantle interface at a depth of ~50 km in a paleo-subduction channel. The highest-grade (blueschist-facies to eclogite-facies) meta-mafic rock shows almost no retrogression, implying rapid decompression. The two meta-melanges, which contain blocks of HP rocks and antigorite serpentinites within a garnet-bearing pelitic matrix, are both sandwiched between relatively lower pressure-temperature pelitic or psammitic schists (up to 100 °C cooler)—a framework likely resulted from tectonic extrusion. Exhumation of the Yuli belt’s HP metamorphic rocks is a geologically fast but complex journey that might have been driven by buoyancy at great depths (because serpentinite and metapelite are less dense than mantle rocks surrounding the subduction channel), and facilitated by collision-related tectonic forcing at mid- to shallow crustal levels.
Geochemistry of the Late Eocene Luzon Granitoid Complex, Philippines

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The Late Eocene (Zircon U-Pb: 34-37 Ma) Luzon granitoid complex (LGC) is composed of very silicic (SiO\textsubscript{2}: 72.8-78.5\%) intrusive rocks such as granodiorites, tonalites, and quartz diorites. These batholithic units which can be found in the Luzon Central Cordillera and Sierra Madre are very distinct from younger typical calc-alkaline to adakitic units (Late Oligocene-Pleistocene) in the Luzon arc. Intrusives of the LGC are closely associated with basaltic swarm dikes and are typified by the presence of mafic microgranular enclaves (MMEs). Major oxide chemistry shows a general peraluminous composition resembling S-type granitoids and exhibits calc-alkaline affinities. Chondrite-normalized trace element compositions show pronounced negative Eu anomalies (Eu/Eu*: 0.2-0.8) accompanied by varying degrees of LREE enrichment. Discrimination diagrams utilizing HFSE/LILE ratios and LREE/HREE ratios reflect a primitive- to typical-oceanic arc environment. Furthermore, biotite mineral chemistry data from one intrusive sample, which also reflected a peraluminous character, showed crustal derivation. Based on these new age dates and geochemical data, we assume that these peraluminous granitoids are most likely formed from anatectic melting of a primitive arc crust during the Eocene due to an episode of asthenospheric upwelling.
Mixing, fluid Infiltration, Leaching and Deformation (MILD) processes on the subducting slab-mantle wedge interface

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The boundary between the subducting slab and the overlying mantle wedge, i.e. slab-mantle wedge interface, is a site of complex physical and fluid-related chemical processes which directly affect the chemistry of arc lavas. Localities preserving rocks that once represent the slab-mantle wedge interface thus provide unique insights to what comprises this boundary and the processes that occur on it.

In this work, the whole rock composition of the blocks and the surrounding matrix of the Dalrymple Amphibolite, exposed at the base of the ultramafic section of the Palawan Ophiolite, is investigated. The major and trace element contents of the metamafic blocks indicate a mid-oceanic ridge basalt protolith similar to the mafic crustal section of central Palawan Ophiolite. The matrix surrounding the blocks exhibit highly variable mineral assemblage. Groups of components exhibiting similar behavior were identified (Group 1 Ti, Al, Zr, Th; Group 2 Cr, Ni and MgO) by calculating their correlation coefficients. These groups indicate mixing of metasedimentary (metased1) and metamafic (metamafic2A/EA) end-members to form the matrix. Mixing proportions of the end-members were estimated by employing regression analysis between measured and modelled concentration of fluid immobile elements (Cr, Ni, Zr, TiO2 and Al2O3). The modelled and the measured matrix compositions were then used as the original (unmetasomatized) rock and the altered rock respectively in the isocon analysis.

Mass balance calculations indicate that the measured matrix compositions record losses in fluid mobile components (e.g. SiO2, CaO, P2O5). Losses in other elements/components (e.g. MnO, HREE) are controlled by their mineral assemblage (e.g. presence or absence of garnet). This suggests a prograde fluid infiltration which likely occurred following the mixing process and preferentially leached out elements which are either fluid-mobile (e.g. SiO2, CaO, P2O5) or are not incorporated into the growing minerals in the matrix (e.g. HREE on garnet). Gains in K2O, Rb, and Ba in the matrix samples are meanwhile linked to the extent with which their minerals are replaced by secondary phases (e.g. kyanite replaced by muscovite). This suggest a latter hydration event linked to retrograde metamorphic stage.
Thermal events in the Palawan Island: evidence for a pre-Mid-Miocene metamorphism and Mid-Late Miocene exhumation

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In Palawan, folded Mesozoic meta-sedimentary series are over-thrusted by Eocene to Cretaceous ophiolitic slivers. Ophiolitic emplacement, deformation and metamorphism are typically considered a direct result of a single tectono-thermal event following the closure of the proto-South China Sea and collision of the intervening blocks. In this contribution, we present new thermochronological ages (apatite and zircon fission track; ZFT-AFT), estimates of the maximum metamorphic temperatures (Raman Spectroscopy of Carbonaceous material) and structural considerations in Northern Palawan aimed at constraining the conditions and timing of metamorphism and deformation.

Our results suggest: 1) Metamorphism pre-dates the main folding and exhumation phase, as derived from the distribution of reset vs. partially reset thermochronological ages and RSCM maximum metamorphic temperatures generally coincident with the main regional folds (i.e. isotherms subparallel to the stratigraphic boundaries); 2) The onset of folding and cooling of the studied continental affinity Cretaceous meta-sedimentary rocks occurs at ca.14.7Ma ±0.6Ma (ZFT-ages) and proceeds until at least ca.8-10Ma (AFT ages). 3) 12.5±1.5Ma AFT-ages in the Eocene to Miocene (?) sediments of southern Palawan suggest that the main cooling (and exhumation?) phase affected the whole island.

Future geodynamics models are required to include our first-order data-driven interpretations, namely 1) peak-metamorphic conditions are reached post-Up.-Cretaceous (depositional age of oldest studied meta-sediments) and pre-Mid-Miocene (14.7Ma ±0.6Ma ZFT-age), temporally coincident with the opening of the South China Sea; and 2) continental affinity series in northern and southern Palawan record a main contractional deformation, rock cooling, and probable subaerial exposure, erosion and exhumation (correlative to the offshore “red-unconformity”?) starting from 14.7Ma ±0.6Ma and likely proceeding until ca. 8-10Ma.
Petrogenesis of Cretaceous alkaline igneous rocks in Southern Palawan

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Palawan island is dominantly composed of the Eocene central Palawan Ophiolite (CPO) and the Cretaceous southern Palawan Ophiolite (SPO). These ophiolitic sequences were obducted during the collision of the PCB with the Philippine Mobile Belt (PMB). Recent fieldworks conducted in Palawan have shown that exposures of the crustal section of the SPO are very limited compared to the extensive outcrops of the CPO. The petrological characteristics of alkaline intrusive units associated with the SPO are investigated in this work.

Biotite-bearing gabbros and syenites occur as boulders in rivers in Brooke’s Point, southern Palawan. The former are more abundant and are often larger compared to the latter. Biotite-bearing gabbros are medium to coarse-grained and characteristically contain biotite. In contrast, blocks of syenite are smaller and less abundant. They are pinkish in color and consist almost exclusively of medium-grained feldspars.

Petrographic analysis of the biotite-bearing gabbros reveals the following paragenesis: plagioclase, biotite, clinopyroxene, ± olivine. Biotite typically occurs as interstitial grains suggesting their late-stage formation. In one sample (SBG-04), biotite inclusions occur exclusively in the outermost domain of a zoned clinopyroxene. Meanwhile, the syenites mainly consist of alkali feldspar (~90%). Most of these alkali feldspars exhibit perthitic texture with exsolutions of albite connected and comprising the interstitial phase. Minor biotite, alkali amphibole, and sphene are also observed in some samples.

Uranium-lead (U-Pb) dating of a biotite-bearing gabbro and syenite yielded ages of 100.73 ± 1.07 Ma and 102.97 ± 1.07 Ma, respectively (Dycoco et al., 2021). The phase assemblages of both mafic intrusive units are uncharacteristic of typical ophiolites and may indicate alkaline magmatism in the area during the Cretaceous. Mineral chemistry analysis will also be done to constrain the petrogenesis of these rocks and further elucidate how these rocks fit in the geologic evolution of Palawan island.
Seismotectonics of Sulawesi, Indonesia

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Sulawesi is an Indonesian island located at the intersection of the Australian, Sunda, and Philippine Sea plates. Sulawesi served as a natural laboratory for studying the complex tectonic interactions of the major plates. The unique K-shape of Sulawesi was the consequence of multiple continuous tectonic events since the Cretaceous. As a result, the island reflected the complex tectonic setting and was seismically active. We aim to study the seismotectonic behavior in Sulawesi Island using the updated earthquake and focal mechanism datasets and additional supporting data. We divided Sulawesi into two depth categories based on the earthquake depth distribution: the shallow part (60 kilometers), which was then divided into six regions, and the deep part (60–400 kilometers), which is related to the Celebes and Sea slabs. For the shallow part, we analyzed seismicity distributions and focal mechanisms in the framework of Sulawesi’s tectonic settings. Our results revealed a lack of seismicity near the North Sulawesi Trench’s center and the northern Palu-Koro fault. These results are interesting since the previous studies indicated that these two zones have a high slip rate. Regarding the deep part, we investigated the geometry and stress patterns of the Celebes and Sula slabs using linear fitting and stress state projection methods. We found that the Celebes Sea was subducted southward with an average geometry (strike 920 and dip 710), while the Sula slab was subducted north-northeastward with an average geometry (strike 2530 and dip 730). Furthermore, the western Sula slab exhibited an absence of earthquakes at 60–230 km depth. Based on our comprehensive analysis, we derived the following well-founded conclusions: (1) A seismic gap or aseismic slip from the Celebes Sea subduction might contribute to the lack of seismicity near the center of the North Sulawesi Trench. (2) Northern Palu-Koro was beyond the Makassar and North Sula blocks’ high relative motion, resulting in inactive seismicity. (3) The absence of seismicity at 60–230 depth in the western Sula slab might be related to the shallow-slab detachment due to the high-velocity rate of the Indian–Australian plate in the first stage of the Early Miocene collision.
**Significant Earth's response to the 2022 Tonga volcano eruption shock wave across Western Pacific from various instrument observations**

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On 15 January 2022, a large underwater violent volcano erupted at Tonga with volcanic ash and gasses reaching into the air. A surface-wave magnitude (Ms) of 5.8 has been estimated by USGS. The eruption was well captured from space to send tsunami wave rippling across the Pacific Ocean. A number of places around the globe have reported perturbation in local air pressure following this event. Theoretically, a violent earth near-surface explosion expected to send many types of waves through Earth’s atmosphere: infrasound waves, Lamb waves, acoustic-gravity waves, and signals from tsunamis across the globe. However, it is never recorded as strong as this event. The multiple earth system responses and its interactive mechanism from each observed specific phenomenon provide an opportunity to examine it in detail.

Taiwan island is located at western Pacific with distance about 8500 km far from the explosion source. The main and its surrounding islands have equipped various instruments to monitor regional weather, earthquake, tsunami and louds of environment with high spatial density. During this volcano eruption, the fast variation of earth system is well monitoring. Evidences have been recorded to demonstrate a regional detail response of this unique event. Observations have recorded from air, water and solid ground. In this study, we collected the data from the air pressure gauges, costal tidal gauges, ocean bottom hydro-pressure gauges, infrasound sensors, digital microphone and seismometers from Taiwan, Indonesian, New Zealand and Australia. We analyzed those instrument records to document individual observed phenomenon and to interpret its interaction. Results of this study indicated a special tsunami wave created by the Tonga explosion induced shock wave. It followed a different mechanism for its travel time and wave high from a classic tsunami which is derived by a sudden displacement of the sea floor by an earthquake or underwater landslide.
The Rupture Process of the 2022 Guanshan Earthquake and Chishang Earthquake in Longitudinal Valley, Eastern Taiwan from Joint Inversion of Seismological and Geodetic Data.

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In September 2022, the two earthquakes occurred in close proximity in space and time in Longitudinal Valley (LV) viewed as a suture zone of arc-continent collision between Eurasian plate (EP) and Philippine Sea plate (PSP). The earlier event occurring on September 17th is called Guanshan earthquake with Mw 6.5; the later one with greater moment magnitude (Mw 7.0) is called Chishang earthquake that just occurred a few kilometers away from Guanshan earthquake on September 18th. Based on the report of focal mechanism and the aftershock distribution observed from the Central Weather Bureau (CWB), their seismogenic structure is the west-dipping Central Range fault which has generated some significant events at western side of LV (e.g., 2006 Taitung earthquake and 2013 Ruisui earthquake). In this study, we build the finite fault model constrained by telesismic waveforms (P, SH, Rayleigh, Love), strong motion records, static and high rate GNSS to resolve the rupture process of these two earthquakes. In the inversion scheme, we employ Wavelet and simulated Annealing Slip (WASP, Koch et al., 2019; Goldberg et al., 2022) which uses nonlinear simulated annealing algorithm to optimize the slip amplitude, rake angle, initial rupture time, and rise time within each subfault in the wavelet domain. For Guanshan earthquake, our results display that the cumulative slip distribution mainly concentrated in the south of the epicenter with maximum slip of ~1.2 m. The kinematic rupture process demonstrates that the source has weak initiation and rupture circularly for ~12 sec. For Chishang earthquake, the cumulative slip distribution is primarily in the north of epicenter. Here, the shallow asperity with the maximum slip of ~5m is near the Yuli township which has severe damaged buildings reported. The kinematic rupture process displays that the source has weak initiation and rupture front progressively accelerate toward north with total rupture duration ~20 sec.
Application of the real-time seismic wavefield on the earthquake early warning system

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The earthquake early warning system (EEWS) is working based on the real-time seismic data. After the procedure of the data processing and the estimating related source parameters, the EEWS is able to send warnings to the alerted areas. In order to timely issue warnings, limited number of triggered stations would be used in the initial stage of the EEWS. However, the uncertainties of the estimations would be larger than that the EEWS used enough data. The EEWS can be considered as two modes. One is point source mode, the other is the wave field mode. In the point source mode, the information of the P wave is used to estimate the origin time, epicenter, depth and magnitude. Consequently, the predicted seismic intensities are made by using the ground motion prediction equations. In the wave filed mode, the real-time observed seismic intensities are constructing a wave field that can be used to predict the seismic intensities in the next second. The challenge of the EEWS comes from a mega earthquake (typically with a magnitude of 7 or larger) and its intense aftershocks. The magnitude of the main shock might be underestimated because of lack of considering the effect of the finite fault, site effect, and the directivity. The warnings could be lost for the large aftershocks because the P waves might be difficult to be recognized. The false alarm might be happened when two small earthquakes occurred within a short time interval. Because the procedure of the association could be wrong, P-wave arrivals from the two earthquakes might be considered coming from the same event. As a result, the EEWS overestimate the magnitude and the predicted intensities as well. The purpose of this study is to use the wave field concept to overcome the previous problems and try to reduce the processing time.
Introduction of the project of establishing the Earthquake and Tsunami Submarine Observation System between Taiwan and the Philippines

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In order to improve the capability for offshore earthquakes and tsunamis monitoring off eastern Taiwan, the Central Weather Bureau, Taiwan, has already completed the construction of the first to third phases of the submarine cable “Marine Cable Hosted Observatory” (MACHO) system before December 2020. The total cable length is 620 km and six real-time monitoring stations has been installed. The maximum depth of the deployed cable is at about 5700 meters deep. The implementation of MACHO has an advantage of extending the coverage of existing the Taiwan seismic network to the offshore, providing more accurate and real-time seismic data for offshore earthquakes monitoring. Furthermore, menaced by the potential tsunami threat in the Manila Trench in southern Taiwan, the Central Weather Bureau plans to set up the fourth phase of the submarine cable system between Taiwan and the Philippines. This system is expected to deploy ca. 800 km submarine cable between the Pingtung Fangshan Submarine Cable Station and the North Luzon Submarine Cable Station, and six real-time seismic observation stations will be deployed along the way. This project is already approved by Taiwan government, the network design and landing site survey are ongoing. The Philippine counterpart for future network construction, operation and maintenance is the Philippine institute of volcanology and seismology (PHIVOLCS). Nowadays, only few countries of the world have employed submarine cables for real-time monitoring and hazard prevention. It is hoped that through the promotion and implementation of this plan, the disaster prevention and early warning capabilities of Taiwan and the Philippines can be largely improved and be more effectively. Furthermore, through the data collected from this project, more young students and researchers from the Philippines and Taiwan can gain more knowledge of the tectonics of the Marina subduction zone and related scientific issues.
Climate change and extirpation of Taiwanese population of Scaphechinus mirabilis A. Agassiz, 1864 during the Pleistocene–Holocene transition

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Biogeographic distribution of Scaphechinus mirabilis mainly occurs in the temperate, sandy coastal seafloor north of Taiwan. However, it is one of the most abundant fossil echinoids reported from the Cenozoic strata of Taiwan. Estimated that more than one million individuals had inhabited shallow coast of Taiwan. What triggered the local demise of Taiwanese population remains as a mystery until now. This study employs multi-proxy approaches to provide crucial evidence that S. mirabilis was a cold water species lived around Taiwan during the Last Glacial Period, then vanished abruptly during the rapid warming phase after the Younger Dryas.
New fossil species of the genus Laganum (Echinodermata: Echinoidea) from the Kueichuling Formation (late Miocene – Pliocene), northern Taiwan

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Taiwan is located in the collision zone between the Philippines Sea Plate and the Eurasian Plate. The fossil-bearing unit Kueichuling Formation (late Miocene – Pliocene) was deposited in the foreland basin during the active phase of rapid uplifting of Taiwan known as the Penglai Orogeny. Thus, fossil echinoids (n = 61) described here show some degrees of distortion. Digital retrodeformation was applied to specimens with well-exposed oral surfaces in order to evaluate the degree of measuring uncertainty. After comparison with specimens (n = 104) of extant taxon L. laganum, there are two distinct fossil species Laganum sanxianensis sp. nov and L. hsiungii sp. nov, each with two morphologic trends. This represents the earliest occurrence of the family Laganidae Desor, 1857 reported from Taiwan. Possible early origination(s) of Taiwan fossil faunas are discussed.
Provenance and tectonic setting of the clastic turbidite sequences in southwestern Mountain Province: Clues from the geochemistry and geochronology of the Balili Formation

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The Balili Formation is exposed in the Bauko and Sabangan municipalities, southwestern Mountain Province in Central Cordillera, northern Luzon. It consists of a lower member of red and green sandstone-siltstone-mudstone sequences and an upper volcanic conglomerate sequence. It is reported to be coeval with the extensively studied Late Oligocene to Early Miocene Zigzag Formation in Baguio located in the southern portion of the Cordillera Range. Previous geochemical investigations on the Zigzag Formation provided critical information regarding the tectonic evolution in the Baguio Mineral District. This study aims to determine the provenance and tectonic affinity of the Balili Formation using whole rock geochemical compositions of the clastic rocks in order to provide clues to the geodynamic evolution of the southwestern Mountain Province.

The exposures in Bauko, Mountain Province is characterized by alternating fine-grained clastic units, with minor thin- to medium-bedded fine- to very fine-grained sandstones. The northern exposures in Sabangan and Sagada, meanwhile, exhibit increased grain sizes, becoming medium-to thickly bedded, medium- to coarse-grained sandstones. These clastic sequences were identified as a deep marine turbidite deposit. Ages of the zircons derived from the sandstones reveal a Middle Miocene (13.32 ± 0.41) age of the source rocks. The major oxide and trace element geochemistry indicate an intermediate to basic source with felsic source contributions. Several tectonic discrimination diagrams indicate an oceanic island arc and fore arc affinity of the source region. Depleted LREE and flat HREE signatures with significant positive Eu anomalies in samples normalized with Post-Archean Australian Shale suggest derivation from a less geochemically fractionated source rock. Paleoweathering proxies reveal weak to moderate weathering of the source rocks consistent with a relatively dry or arid paleoclimatic condition.
Major and trace elements geochemistry of clastic sequences from Ilocos Norte, Philippines: Implications for provenance, tectonic setting and paleoclimate conditions

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Whole-rock geochemical data from the clastic sequences of the Bangui Formation (Late Eocene - Late Oligocene) and Bojeador Formation (Early Miocene) from Ilocos Norte, Philippines were examined to obtain information on their provenance and tectonic setting. The geochemical data also gave clues on paleoclimate conditions in the depositional area. The results show that the sedimentary units in Ilocos Norte were derived from mafic igneous rocks with an oceanic island arc setting affinity. Paleoclimate proxies such as the major oxide ratios of MgO/Al2O3, CaO/K2O, K2O/Na2O, MnO/CaO and trace elements of Sr/Cu ratios indicate deposition in a transitional humid (warm and wet) to arid (cold and dry) condition during the Late Eocene to Early Miocene. Relatively low MgO/Al2O3, CaO/K2O, and high K2O/Na2O, MnO/CaO values reflect humid conditions and vice versa. Sediments from Bangui formation have relatively lower values of MgO/Al2O3 (~0.20-0.25), CaO/K2O (~1.0-3.0), and higher values of CaO/K2O (~1.0-5.0), MnO/CaO (~0.02-0.06) compared to MgO/Al2O3 (~0.25-0.35), CaO/K2O (~1.5-11.0), K2O/Na2O (~0.40-2.0) and MnO/CaO (0.01-0.03) of Bojeador Formation. The Sr/Cu ratio of the Bangui Formation is less than 5.0 (humid condition) while Bojeador Formation is greater than 5.0 (arid condition). Globally, the paleoclimate from Late Eocene to Early Miocene transitions from cold to warm but the Ilocos Norte sediments data says otherwise. The position of the inter-tropical convergence zone (ITCZ), a major source of precipitation, is the possible reason for the recognized paleoclimate in northern Luzon during these epochs. This new information can contribute to understanding the evolution of the northern part of the Philippine Island Arc system.
A tale of two orogens-Taiwan and Mindoro

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The Taiwan and Mindoro islands are located on the northern and southern ends of the Malina trench, and both orogens result from the deformation of the continental margin of the Eurasia plate. Comparing the exhumation histories of both orogens allow us to discuss the mechanism of mountain building of two orogens.

In Taiwan orogen, the timing of the mountain building starts from ca. 6-8 Ma, which can be identified using ZrnFT, Ar-Ar, and the timing of the developing foreland basin. For Mindoro island, we combine with ZrnFT, ApaFT, and ZrnHe to constrain the timing of the exhumation. It shows oldest ZrnFT ages are ca. 6-7 Ma. We further constrain that the latest stage of granite age in the rifted continental crust is ca. 13Ma indicating the collision should be later than this age. In addition, the ApaFT and ZrnHe ages for the granite are ca. 6Ma inferring a rapid cooling age which is consistent with regional ZrnFT dates. Those data imply the timing of mountain building of Mindoro orogen is ca. 6-7Ma which is similar to the Taiwan orogen.

Considering both orogens have similar timing of mountain building, we suggest that while the Philippine Sea changes the motion to NW trending at ca. 7-8Ma and Eurasia continental margin subducts to the Philippine Sea plate and Philippine Mobile Belt, respectively, that results in both orogens deforming simultaneously.
Imaging Subsurface of the Northern Philippines Using Autocorrelation of Noise Data

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The Philippine archipelago is made up of various terrains such as ophiolites, island arcs, and continental fragments. Knowing the variations of crustal thickness across the Philippines can help understand its tectonic evolutions. Previous work has studied the crustal thickness of the Philippines using magmatic and amagmatic contributions (Dimalanta and Yumul, 2003) and gravity data (Parcutela et al., 2020). In this study, we propose to analyze noise data recorded by stations deployed in northern Luzon and NW Mindoro to image the crustal thickness beneath. Seismic interferometry of noise data has been the mainstream of seismological study in the past two decades. While cross-correlation of two stations reflects characteristics of media in between, auto-correlation of single station reveals signals of vertically two-way travel path between surface and subsurface discontinuities. By stacking the auto-correlation function over a period time (e.g., one month), we expect the those of Moho reflections can be enhanced and the crustal thickness can be estimated provided existing velocity structures.
Along-strike subduction heterogeneity in the Manila Trench: Coupling and seismological implications

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The nature of convergence in western Luzon is inherently complex, with the subduction of heterogeneous South China Sea slab along the Manila Trench (aseismic ridge and seamount subduction, elastic thickness, accretionary vs. erosional nature of the margin). In addition, a slab tear exists, further complicating the geologic imprints in the overriding plate. This, in turn, lends to the strain variations in the subduction interface. These features ultimately control the deformation segmentation in the megathrust. The present work attempts to image the heterogeneity of the subduction interface in offshore western Luzon, seismogenesis, and strain in the northern, central, and southern portions of the Manila subduction zone. Recently compiled gravity and bathymetric datasets were analyzed to isolate the high-frequency and low-amplitude signatures associated with subducted reliefs. In addition, a detailed analysis of seafloor morphology was conducted to deduce the forearc response to these subducted reliefs. Buoyancy variations of the subducting slab and coupling in the interface were also assessed from elastic thickness calculations. These will then be compared with seismicity and strain rates. The evaluation and synthesis of these various subduction parameters can provide a snapshot of the earthquake potential of the megathrust.
Gravity anomalies offshore western Luzon: Clues to ophiolite emplacement and persistent strike-slip tectonics in the South China Sea eastern margin

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Gravity data from the Earth Gravitational Model (EGM 2008) and various ground gravity surveys were merged and processed to produce an updated Bouguer anomaly map for western Luzon. Regional-residual separation was carried out to differentiate signals of deep sources from those arising from shallow bodies. The Bouguer anomaly map was subjected to further processing to produce the first vertical derivative anomaly map, which helps enhance near-surface density features and structural boundaries.

An examination of the residual and first derivative gravity anomaly maps reveals a prominent arcuate belt of gravity high stretching from west of Zambales towards Ilocos Norte. It is worth noting that similar high gravity anomaly signatures characterize the Zambales Ophiolite Complex and the Dos Hermanos Mélange in Ilocos Norte. This observation is consistent with the results of other studies showing a link between the Zambales Ophiolite Complex and the Dos Hermanos Mélange. The vertical derivatives also highlight the critical role of shearing in the north-south translation of these ophiolitic bodies. Information from gravity imaging and recent geologic datasets in western Luzon indicates the persistent strike-slip deformation in the area responsible for the present configuration of the tectonic provinces.
Forearc morphological heterogeneity in the Manila Subduction Zone: A result of seamount subduction?

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The complex forearc morphology in offshore western Luzon is attributed to the subduction of the heterogeneous South China Sea basin along the Manila Trench. The Vigan High is one of several bathymetric features in the Manila Trench region. This bathymetric high is a flat-topped feature bounded by submarine canyons. Previous models proposed that it was associated with the forearc uplift due to accreted fragments of the Scarborough Seamount Chain (SSC) (South China Sea extinct spreading ridge) subducted at 16°N latitude. This preliminary study attempted to map the bathymetric high using new seismic reflection data to understand its geologic characteristics. The seismic reflection data were gathered from the recently concluded LGD-2201 marine scientific cruise and the ORV-041 cruise. Analysis of the seismic reflection profiles indicates faults and fractures bounding the Vigan High. NW-SE trending major faults were identified in the seismic profiles, bounding the Vigan High to the north and south, corresponding to the submarine canyons. The delineated major faults are interpreted as offshore strands of the Philippine Fault Zone (PFZ). Available gravity and magnetic data were also used in this study to complement the seismic reflection data. A combination of the first and second-order horizontal and vertical derivatives indicate NW-SE trending major faults bounding the bathymetric high. The derivative maps support the idea that these faults may correspond to the offshore extension of the PFZ. The gravity and magnetic data show that high gravity and magnetic signature patches characterize the Vigan, and this might suggest that the Vigan High is unrelated to a subducted seamount. Instead, we propose that the present configuration of this bathymetric high is affected by differential erosion across the offshore faults, resulting in the submarine canyons bounding the Vigan High.
Tectonic controls on the BSR distribution in the northern Manila Trench forearc

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Gas hydrates are clathrates formed from hydrocarbon gases and water molecules at low temperatures and moderate pressures. Bottom-simulating reflectors (BSRs) in seismic reflection profiles define the boundary between gas hydrate-bearing zones and free gas-charged sediments, also corresponding with the base of the gas hydrate stability zone. The BSRs are concentrated in two regions along the northern Manila Trench forearc – in the frontal wedge with depths ranging from 285 m to 359 m below the seafloor and in the western portions of the North Luzon Trough, at depths of 714 m to 812 m.

A gently dipping subducting slab forearc with a thick incoming sedimentary cover of continental provenance typifies the northern segment of the Manila Trench. Accretion of organic matter-rich, continentally-derived sediments along the frontal wedge promotes the formation of thrust faults and fluid migration structures, leading to an increased heat advection through upward fluid migration. This is evidenced by the higher heat flow values in the area. This fluid migration system effectively transports hydrocarbon-rich fluids both of biogenic and thermogenic origin within the frontal wedge, forming BSRs at shallow depths.

On the other hand, the North Luzon Trough is composed of turbiditic sequences inferred to be growth strata dominantly sourced from the Luzon arc, deposited contemporaneously to the uplift and accretion along the frontal wedge. Several intervals characterized by chaotic, low-amplitude reflectors were also observed and interpreted as mass transport deposits (MTDs). These deposits appear to be sourced from the collapse of the frontal wedge, possibly due to the oversteepening of slopes or overpressure associated with gas hydrate dissociation. Due to these characteristics, limited hydrocarbon sources are inferred for the North Luzon Trough. Fluid migration along the landward-titled sedimentary sequences resulted in the concentration of gas hydrates to the western portions of the basin.

These observations show that the BSR distribution within the northern Manila Trench forearc region is controlled mainly by the tectonic configuration of the subduction system. The distribution of faults and other fluid migration pathways, the provenance of sediments, and the compression experienced by the region all contribute to the gas hydrate system in the area.
POSTER PRESENTATIONS:
Solid Earth
The Philippine GNSS Network


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The Philippine GNSS Network started in 1991 as the GPS project, a result of the collaboration between PHIVOLCS and two French institutions – Université de Paris VI and Institut Géographique National under the Republic of the Philippines-France Collaborative Project on Seismotectonics. Its objective was to analyze the mechanical behavior of the Philippine Fault Zone (PFZ) in Leyte and Masbate Islands. In 1996, PHIVOLCS collaborated with IESAS, Taiwan to establish the Philippine GPS campaign network in Central and Northern Luzon. The collaboration is still on-going, with the entire Luzon network composed of around 50 Continuously Operating Reference Stations.

Several foreign institutions like the Kyoto University, UNAVCO, Indiana University, and JICA/JST have also teamed up with PHIVOLCS to conduct GPS campaigns in Luzon and Mindanao. PHIVOLCS also has a strong partnership with the National Mapping and Resource Information Authority’s Philippine Active Geodetic Network (PAGeNet), a national array established for modernizing the Philippine Geodetic Reference System.

In April 2008, PHIVOLCS, in collaboration with NCKU under the RP-Taiwan Project, installed 10 CORSs along the Valley Fault System. Two years later, 8 CORSs were installed in Mindoro Island under the RP-Taiwan Project, with the objective of studying the collision between Palawan and the Philippine Mobile Belt. In more recent years, the same collaboration yielded the densification of the VFS network into 27 CORSs comprised of 4 dual and 23 single frequency receivers, as well as the eventual establishment of 20 CORSs in Samar and Leyte, 8 CORSs in Masbate, 2 CORSs in Romblon, 2 CORSs in Mindanao and 1 in Palawan.

In 2009, a grant of $390,000 by the Department of Science and Technology Grant-In-Aid project led to the acquisition of new GPS receivers, the reoccupation and rehabilitation of old GPS networks along the Philippine Fault and the study of crustal deformation patterns of the Cotabato-Sindangan Fault, a 300-km long active fault cutting across northwest to southeast of Mindanao.

In the past 5 years, PHIVOLCS installed 23 CORSs in Visayas and Mindanao with real-time monitoring of displacement and velocity capabilities.

At present, PHIVOLCS maintains a national network of 300+ GNSS campaign sites and CORS, devoted to the study of crustal deformation patterns along the PFZ and other minor yet potentially active faults in the country.
Evaluation of Sulfuric Acid-mediated Weathering and CO2 Fluxes in Southwestern Taiwan

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In recent years, many countries have been committed to achieving “Net Zero Emissions” in response to ongoing global warming. However, in addition to direct anthropogenic CO2 emissions, natural weathering processes or indirect anthropogenic sources also contribute to CO2 fluxes. Aside from carbonic acid-mediated mineral weathering, sulfuric acid also plays an important role in the weathering process in orogenic belts such as Taiwan. Pyrite, the sulfide minerals enriched in the metasediment and mudstone of southwest Taiwan, produces sulfuric acid through the oxidation reaction with water. Compared with carbonic acids, sulfuric acids react with carbonates faster and would dominate the weathering reactions. Thus, sulfuric acid-mediated weathering of carbonate and silicate rocks would lead to (in)direct CO2 fluxes that affects the carbon cycle. While the role of sulfuric acid-mediated weathering is not comprehensively considered in the existing CO2 fluxes evaluation models, which also needs more temporal and spatial supporting data. This study focuses on seven main rivers of southwest Taiwan, time series sampling will be done in the span of the dry and wet seasons. The river water major ions and dissolved inorganic carbon are measured using ICP-OES and the titration method, respectively, then will be used to estimate the carbonic and sulfuric acids triggered weathering and CO2 fluxes. The sulfur isotope ratio is measured to further estimate the relative contributions of natural and anthropogenic sulfuric acids. So far, we have sampled at two-time points by the end of the wet season. Preliminary results show that the dissolved solids in river water mainly derived from sulfuric acid-mediated weathering, with approximately four-fifths of carbonates and one-fifth of silicates. The time series sampling will continue to assess the controlling factors of weathering in southwestern Taiwan and their influences on CO2 fluxes under different seasons, precipitation, and temperature conditions.
Metamorphosed forearc relics preserved in the Taiwan orogen: new evidence from the Yuli belt

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Cenozoic high-pressure (HP) metamorphic rocks in the Yuli belt of the Taiwan orogen record a subduction history involving the Eurasia plate and the Philippine Sea plate. These HP rocks are mainly of igneous or volcaniclastic protoliths, ranging from basaltic, gabbroic, andesitic to plagiogranitic in bulk composition. The HP rocks occur as blocks in several mélangé units and have been interpreted as fragments from a metamorphosed ophiolite of unknown origin. In this presentation, we report the first U-Pb zircon dates of the metaplagiogranites and associated metagabbro from the Chinsuichi mélange in the southern Yuli belt by secondary ion mass spectrometry (SIMS) analysis. The metaplagiogranites contain glaucophane ± omphacite, attesting to subduction metamorphism. The whole-rock compositions of the studied samples show negative niobium-tantalum anomalies. SIMS U-Pb zircon dating yielded consistent dates of 17.4–16.9 Ma, which are interpreted as magmatic crystallization ages. The dated zircon grains show δ18O averages of 3.9–5.0 ‰, implying that the ultimate source rocks were mantle-derived. The protoliths of the HP metagneous rocks likely originated from a nascent forearc setting related to an early Miocene subduction initiation. As a consequence of plate convergence, this newly-formed forearc crust might have been completely destroyed by subduction erosion and transported into the subduction channel. Our new finding challenges some previous models that postulate the South China Sea origin for the Yuli belt’s metaophiolitic fragments.
Iron and manganese are always considered to share common sources and sinks in the global ocean. However, Fe and Mn also have completely different redox reactivity and speciation that can cause their distributions decoupled. The Greenland-Iceland-Norwegian-Sea region, where the thermohaline circulation originates from, have a complex circulation with different terrestrial inputs. It is thus an ideal location to study dissolved Fe and Mn distribution, and it is also important to investigate the critical role of this Atlantic-Arctic gateway in controlling trace metal cycling in the whole Atlantic Ocean. Our preliminary results show that the distribution of dissolved Fe and Mn are indeed decoupled in the region. Fe has a typical nutrient-type profile; Mn has depleted surface Mn concentrations following by a subsurface Mn maximum, suggesting biological uptake in the surface water and implying a Fe and Mn co-limitation. In terms of sources, dissolved Fe concentrations in the deep water are relatively high near Iceland, but not for Mn, implying a deep water Fe input without Mn. Near Greenland, elevated dissolved Mn concentrations and extended high Fe/N ratios indicate an external input of Fe and Mn from Greenland to the surface water. Between Greenland and Iceland, homogeneous Fe and nitrate concentrations in the deep water imply that physical mixing is significant in the region, but dissolved Mn did not show a similar pattern here. Different internal cycling processes and sources of these two metals deserve to be further studied and the interactions between these two metals and environmental conditions are indeed complex but interesting.
Investigation on the phase transition correlations between pyrrhotite phases using the hydrothermal synthetic method

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Iron sulfide minerals are one of the common minerals on earth, which include mackinawite (FeS), greigite (Fe₃S₄), pyrrhotite (Fe₁₋ₓS) and pyrite (FeS₂). They normally appear in marine or lake sediments. Mackinawite (FeS) is a precursor of the iron sulfide minerals. Mackinawite (FeS) transforms into greigite (Fe₃S₄) or pyrite (FeS₂) in the sulfur-rich environments, and transform into pyrrhotite (Fe₁₋ₓS) in the anaerobic conditions.

It is interesting that pyrrhotite is available in various compositions/structures (e.g., 4C, 5C, 6C, 11C, etc.), however, their correlations were still unclear. This study synthesized pyrrhotites via a hydrothermal method with the pure phase of 3C, 4C and 5C pyrrhotite. The synthetic parameters of iron/sulfur molar ratio, reaction time and temperature were investigated during the crystal-growth process. After sample preparation, an X-ray powder diffractometer was used to identify the crystal structure of pyrrhotite phases.

In the preliminary results, 4C pyrrhotite and 5C pyrrhotite have been synthesized almost close to their corresponding pure phase. Based on our study, it seems the important role played by temperature and time in phase transitions. Therefore, the synthetic experiments will be further carried out and the phase transition mechanism between these pyrrhotite phases will be revealed.
Exploring the spatiotemporal properties of the first higher-mode ambient noise Rayleigh wave in Taiwan

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Resulting from everlasting energy coupling between ocean waves and solid earth, microseisms are dominant signals in seismic records. Applying seismic data to noise interferometry, previous studies have shown that the ambient noise observed in Taiwan is dominant by fundamental mode surface waves in the frequency band 0.2-0.5 Hz, namely, short period secondary microseism (SPSM). However, under particular weather conditions and geological structures, numerous studies had reported that body waves and higher-mode surface waves could be generated efficiently. Taking advantage of the diversity of geology and bathymetry of Taiwan, we aim to investigate the excitation mechanism from the spatiotemporal distribution of higher-mode ambient noise surface waves. This study shows that the 1st higher-mode and fundamental mode Rayleigh waves could coexist in the SPSM frequency band. The temporal excitations of the 1st higher-mode Rayleigh wave are closely related to the monsoon system, while the characteristics of spatial distribution are sensitive to the sedimentary structures. Moreover, with dispersion curve measurements, we show that the published velocity models of Taiwan island tend to overestimate velocities of shallow crust in western plains. Based on the new dataset proposed in this study, we could probe shallow structures in detail in a near future.
Deciphering the mysteries in serpentinites from the Yuli belt: origins and metamorphic conditions

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Serpentinites and associated meta-igneous to meta-volcaniclastic rocks occur sporadically as exotic blocks or layers within metasedimentary schists in the Yuli belt. Some of the meta-igneous-/volcaniclastic rocks contains high-pressure minerals, such as glaucophane or omphacite. These predominantly-mafic/ultramafic rocks are generally interpreted as metamorphosed ophiolitic fragments. However, origin and metamorphism of the serpentinites have long been enigmatic. This study investigates serpentinites from the Fengtien (FT), Wanjung (WJ), Tsunkuanshan (TS), and Chinshuichi (CSC) areas. Based on Cr-spinel composition, protoliths of these serpentinites are distinctively differentiated into two origins. Cr-spinel relics in the FT and TS areas are characterized by moderate Cr# (0.45-0.57), relatively high Mg# (0.59-0.79), but low Fe3+# (< 0.02), suggesting an abyssal peridotite origin. By contrast, the WJ and CSC serpentinites are likely of forearc mantle peridotite origin because of the high Cr# (up to 0.74) and Fe3+# (0.02-0.08), but low Mg# (< 0.6) in their relict Cr-spinel compositions. The peak metamorphic assemblage of the serpentinites is antigorite + magnetite + chlorite + olivine + diopside, indicating a metamorphic temperature around 550 °C. Serpentinites, meta-igneous rocks, and surrounding metasedimentary schists were likely metamorphosed at similar conditions (~1.5 GPa; ~550 °C), i.e. at great depths (~50 km) of a paleo-subduction zone. The Yuli belt serpentinites and associated rocks may represent exhumed materials from the subduction interface.

Keywords: Protolith, Cr-spinel, abyssal, forearc, metamorphism, subduction.
Study on paleomagnetic properties of andesite rocks in Lanyu Island of Taiwan

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Various properties existed within rocks and minerals can provide clues for studying the Earth. Magnetic minerals preserve the geomagnetic information of rocks, which is an indicator of paleogeomagnetism, and thus play a critical role in geomagnetic records. Lanyu Island is generated from plate collisions and mainly consisted of andesite rocks. Only a few geomagnetic studies on Lanyu Island have been conducted, and these studies were done long ago when only low-resolution rock magnetic analyzers were available. In this study, the fundamental properties of magnetic minerals in the igneous rocks of Lanyu Islands based on magnetic results are closely examined. The preliminary results of this study found that the magnetic mineral in Lanyu was magnetite or Ti-poor magnetite. It was observed that more than 80% magnetic minerals were related to a single-domain structure. The magnetic field remained positive direction while a few showed self-reversal phenomenon (anomaly). It seems that the magnetic direction shifted eastward and accompanied by counterclockwise rotation. Further experiments will be kept going. We hope to establish a mutual-interpretation model for macro- (rock magnetism) and micro-magnetic (magnetic structure) results. We also hope to shed light on the geomagnetic variations so as to clarify the paleomagnetic anomalies of Lanyu Island.
Numerical modeling on the sedimentary basins with time-varying kinematic boundary condition

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The depositional system of sedimentary basins contains important information for natural resource exploration and carbon sequestration. In this study, we aim to use a thermo-mechanical model, DynEarthSol, to simulate the formation of sedimentary basins during continental rifting. This model incorporates lithospheric isostasy and sediment loading to the lithosphere deformation. The model records the depositional information (such as the local slope, depth and rate of deposition) of sediment generated by surface processes for later reconstruction of the sedimentary environment and lithology of sediment. With time-varying kinematic boundary condition, the results of the synthetic sedimentary basins show that the patterns of basin sediment unconformities correlate with regional tectonic activity.
The use of communication for disaster preparedness and response in selected landslide prone areas in the Philippines

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The National Disaster Risk Reduction and Management Plan (NDRRMP) 2020-2030 of the Philippines, as well as the Strategic Framework of the United Nations Office for Disaster Risk Reduction (UNDRR) have emphasized the essence of evidence-based and scientific information as foundation of plan of actions to reduce the risk from disasters in the communities. By mainstreaming the risk information, it can strengthen the capacity of communities managing risks. In line with providing evidence-based information and scientific information, Project LIGTAS or Landslide Investigations on Geohazards for Timely Advisories in the Philippines a DOST-funded project works on improving shallow landslide early warning systems in the Philippines by generating site-specific rainfall-landslide thresholds. To better translate the scientific-information and complement their indigenous and local knowledge and practices in relation to disaster preparedness and response, one of the initial steps of the project is to conduct household surveys to know the characteristics of the target stakeholders and look into how landslide information can be better communicated to the specific communities. This study looked into communication and media preferences (and information needs) in terms of the awareness and preparedness of communities. A total of 598 respondents residing in landslide-prone areas in the provinces of Benguet, Albay, Sorsogon, and Northern Samar, Philippines were interviewed using administered questionnaires. Results of the survey showed that respondents from all the provinces prefer and trust sources of information such as TV, radio, barangay officials, and local government units. Moreover, for information campaign materials for landslide information, respondents from Benguet, Northern Samar and Sorsogon preferred radio announcements and posters. While respondents from Albay preferred radio announcements and videos. On the other hand, survey results showed that respondents need more information on things to do before, during, and after landslide events. The results of the survey have shown similarities and differences in terms of availability and preference in sources of information and materials. Thus, in crafting plans for information dissemination and capacity building, use of different platforms is being explored by Project LIGTAS. Furthermore, the results of this study can be the basis in planning for capacity building activities and communication campaigns to strengthen communities with risk-informed stakeholders.
Tracing sediments provenance in Puli Basin using Sr-Nd isotopic compositions

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The Puli basin is the largest basin within the mountains in the orogenic belt of Taiwan. It was formed owing to crustal uplift and river erosion. Faults, folds, and crustal movements might change river flow paths draining through the basin, thereby leading to sediments transported from variable sources. At present, the river, namely Nankang River, flowing through the Puli basin are too small to offer sufficient sediments for the basin. The Zhuoshui River, a larger river nearby, is the potential alternative source providing a large amount of sediment and shows an apparent flow path change from north-south to east-west. Accordingly, the objective of this project is to testify to whether the sediments in the Puli basin come from different areas. Strontium and neodymium isotopic composition of the sediments in the basin and potential provenances were analyzed for source identification. The isotopic data suggest that “Meichi sandstone,” “Lushan formation,” and “River sediment” are sensitively distinguished and could be classified as different End-members. Temporal changes in the basin sediment provenance and their geological significance were determined based on the strontium and neodymium data by the unpaired independent T-test analyses coupled with the Monte Carlo method.
Petrography, geochemistry, and geochronology of gabbros and associated rocks from Pangasinan – northern Zambales

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The Luzon arc is a long chain of north-south trending volcanic centers which extends from Mindoro up to the east coast of Taiwan. Its magmatism is associated with the subduction of the South China Sea Basin along the Manila Trench. Crustal rocks such as gabbros, gabbronorites, tonalites, and diabases occur in the northern Luzon segment of the Luzon Arc. Whether these rocks form part of the Zambales Ophiolite Complex remains to be elucidated. Massive outcrops of isotropic and gabbroic rocks were documented in Pangasinan (e.g. Sual, Bugallon, Mabini, and Infanta) and northern Zambales (e.g. Sta. Cruz). Isotropic gabbros in Bugallon and Sual are cut by northwest and southwest dipping diabase dikes (0.30 – 2 m width), respectively. A tonalite exposure in Mabini is also cut by diabase dikes and its apophyses. Isotropic gabbro in Infanta is intruded by tonalite while the isotropic gabbro from Sta. Cruz exhibits sharp contact with peridotite. In this work, initial petrographic and geochemical analyses and radiometric dating were conducted to provide new insights on the magmatic evolution of the northern Luzon segment.

Petrographic analyses reveal that the gabbros and gabbronorites exhibit orthocumulate and sub-ophitic textures. The crystallization order observed is olivine, pyroxene, then plagioclase which suggests that these rocks formed in an island arc setting. Diabases show sub-ophitic and intergranular textures while tonalites exhibit intergranular and at times myrmekitic texture. Whole rock geochemical analysis of the gabbros, gabbronorities, and diabases indicate an island arc tholeiite signature. Positive trends of FeO*, TiO2, Zr and Y ~ and negative trends of MgO, Cr, and Ni were observed with increasing FeO/MgO. On the other hand, the tonalites show very high FeO/MgO ratio and Na2O and very low amounts of fluid immobile elements such as Zr, Y, TiO2, Cr and Ni. U-Pb dating of a gabbronorite from Sual, Pangasinan yielded an age of 44.33±0.42 Ma. The results indicate that the crustal rocks from Pangasinan and northern Zambales were formed in an island arc setting possibly during the Eocene. Further mineral chemistry and radiometric dating will be done to confirm the genesis of the northern Luzon segment. The relationship of these plutonic rocks to the Zambales Ophiolite Complex will also be further investigated.
Neogene basinal deposition of the
Upper Miocene to Lower Pliocene Santa Cruz Formation in western Pangasinan:
Insights from petrography, geochemistry, and geochronology

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The Upper Miocene to Lower Miocene Santa Cruz Formation occurs as a narrow band west of the Zambales Ophiolite Complex (ZOC) post-dating its amalgamation onto the Philippine arc. Interbedded sequences of conglomerate, calcareous sandstone, siltstone, claystone, and limestone comprise the Santa Cruz Formation and its distribution widens northwards into the western Pangasinan basin. Data on the dominantly ophiolitic source of the sediments in the southern part of the basin have previously published. However, these published studies did not extend north into the western Pangasinan basin forming the impetus of this study. Initial petrographic, geochemical, and geochronological results are presented in this work to provide additional insights into the basin’s Neogene depositional history.

Petrographic analysis of the fine- to very fine-grained sandstones in the basin revealed the presence of abundant detrital plagioclase and clinopyroxene with minor serpentine and amphibole set in a micritic matrix. Trace element concentrations of the sandstones were plotted on provenance and tectonic setting diagrams. Preliminary results suggest a mix of ultramafic, mafic, and intermediate provenance. This is indicated by high to intermediate Co/Th (69.45-6.27) and low La/Sc (0.54-0.08) ratios. Values of Cr/V (0.06-13.66) vs Y/Ni (0.01-6.36) follow the trend of ultramafic to mafic and intermediate source. Low LREE/HREE ratios support derivation from a mafic to intermediate source. In terms of tectonic setting, Ti/Zr vs La/Sc and La vs Th ratios are observed plotting in or near active margin and oceanic island arc setting. One preliminary sandstone sample subjected to geochronologic analyses yielded a Late Miocene (6.36 ± 0.21 Ma) age with zircons exhibiting euhedral crystals with well-defined zoning indicative of a magmatic/volcanic source.

The clastic units in the western Pangasinan Basin may have been sourced from both the crustal section of the ZOC as well as from the then-active western segment of the Luzon Arc. Further geochemical analyses will also be conducted to identify possible variations in the clastic composition in the western Pangasinan Basin. This will hopefully provide additional insights into the deposition of the Upper Miocene to Lower Pliocene Santa Cruz Formation in this region.
Experimental evaluation on arsenic release from goethite through interaction with solutions containing humic acid and compost extract

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Reductive dissolution of goethite has been proposed as the major mechanism of releasing arsenic from sediments to groundwater. Characterized by low redox potential (Eh), solutions containing organic acids have been considering as possible reagents for the goethite dissolution and the following groundwater arsenic enrichment. We therefore performed experiments to evaluate the extent of arsenic release from the interaction between organic solutions and arsenic-containing goethite. Two organic solutions, humic acid (HA) solution and water extracted compost (WEC) solutions were used. The humic acid solution was prepared by dissolving 5 g of humic acid in a liter of DI water, whereas the WEC solution was the supernatant from the mixture of 500 ml of DI water and 600 g of compost composed of residual vegetable leaves and fruit peel after shaking for 60 minutes. The resulting HA contained ~100 ppb arsenic and ~40 ppm iron. In contrast, WEC was nearly free of arsenic and iron. The arsenic-containing goethite was synthesized by mixing arsenic doped Fe(NO₃)₃ and NaOH solutions with initial arsenic concentrations of ranging from 0.1 to 50 ppm. The reaction between the arsenic-doped goethite and organic solutions lasted for 48 hours. In addition, experiments of initial arsenic removal using NH₄H₂PO₄ or NaH₂PO₄ followed by interacting with the organic solutions were also performed for comparison. The results showed that the HA solution did extract the detectable amount of arsenic from the NH₄H₂PO₄ (or NaH₂PO₄) treated goethite that precipitated from the 50 ppm solution. This exacted arsenic represented the co-precipitated species. However, the HA solution can only extract ~70–90% of adsorbed arsenic from the goethite without NH₄H₂PO₄ (or NaH₂PO₄) pretreatment. Similar results occurred for WEC solution, except that the percentage of the adsorbed arsenic recovered from the goethite from solutions with 50 ppm arsenic reduced to < 50%. Both HA and WEC solutions recovered < 5% of arsenic and iron from goethite, indicating that our organic solutions are not the agents responsible for arsenic release from goethite to groundwater. Either higher organic acid concentrations, longer reaction durations, or other reduction mechanisms, such as bioactivities, are required for goethite decomposition to release arsenic.
Co-precipitated As/Fe ratio of synthesized and natural goethite: implications on goethite formation mechanisms

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In the model groundwater arsenic, goethite has been considered as a major contributor by reductive dissolution. It has been known for high arsenic adsorption capacity. However, its ability of co-precipitating arsenic has rarely been investigated. Here, we report data of arsenic co-precipitated in synthesized and natural goethite to provide more constraints on arsenic cycling in environments. The synthesized goethite was produced by mixing iron(III) nitrate and sodium hydroxide solutions. The mixtures were doped with arsenic to have initial arsenic concentrations [As]i of 0.1, 0.5, 1, 10, and 50 ppm. The natural goethite nodules were collected from the Ernjen River sediments in SW Taiwan. These goethite samples were analyzed with arsenic sequential extraction procedures to determine the amounts of adsorbed and co-precipitated arsenic. The results from synthesized goethite showed that arsenic removal amount increased from 0.005 to 1.17 mg/g as [As]i increased from 0.1 to 50 ppm. This apparent increase in arsenic sorption amount, however, corresponded to decrease in removal rate, implying approaching arsenic saturation capacity. Both synthesized and natural goethite have co-precipitated/adsorbed arsenic ratio in the range of 5–9, emphasizing the role of co-precipitation in arsenic uptake. When [As]i increased from 0.1 through 0.5, 1, and 10 to 50 ppm, the corresponding co-precipitated As/Fe ratio were ~4×10−6, ~4×10−5, ~7×10−5, ~5×10−4, and ~1×10−3 respectively, whereas the value for natural goethite were 1–8×10−4, comparable to the synthetic values from [As]i of 10–50 ppm. Apparently, goethite was not direct precipitate from groundwater, since groundwater rarely has high arsenic of 10–50 ppm. Alternatively, we propose that goethite formed from phase transformation of other arsenic-containing minerals. Among them, sulfides represented by pyrite and pyrrhotite are the most common in sediments. In oxidation environments, sulfides gradually dissolve to release iron and arsenic, which are soon re-precipitated to form goethite nuclides on the surface of parental sulfides. Two possible scenarios include complete transformation of parental sulfides to goethite and formation of a goethite crust on parental sulfides. All the resulting goethite can concentrate arsenic with As/Fe ratio higher than those of parental sulfides. Reductive dissolution of goethite will then release arsenic into groundwater.
Liquefaction along the Coastal Areas of Ilocos Sur following the 27 July Northwestern Luzon Earthquake: Constraints from Ground-Penetrating Radar

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The West Ilocos Fault System (WIFS) is described to be the northern extension of the 1200-km-long Philippine Fault Zone and consists of a network of strike-slip, reverse, and normal fault segments. The two major active faults of the WIFS are 1) the NNE-trending Vigan–Aggao Fault which transects the western section of Ilocos Norte and Ilocos Sur and 2) the NNW-trending Abra River Fault which traverses the Cordillera Central. Oblique sinistral movement of these two faults is reported to have formed and developed the 15-km-wide Solsona Basin, where active strands of the WIFS were delineated in its eastern section. Despite its active seismotectonic history, there is limited information on the seismic hazard potential of the WIFS. In this study, we conducted geomorphological analysis, ground penetrating radar (GPR) surveys, and paleoseismic trenching to examine the characteristics of the understudied eastern strand of the WIFS, herein referred to as the East Solsona Basin Fault (ESBF).

The gently sloping scarp (striking N20-35°E and dipping NW) of the ESBF is observed in the municipality of Marcos in Ilocos Norte. Morphotectonic features such as offset streams, truncated spurs, and elevation changes were interpreted from anaglyph images and red relief image maps (RRIM) derived from aerial photos and LiDAR DEM, respectively. Geomorphic markers show a general sinistral movement of the fault with a dip-slip component. Ground penetrating radar surveys conducted along and across the fault scarp reveal discontinuous reflectors, corresponding to minor faults at a depth of about 5 m. A paleoseismic trench was then dug across the fault scarp in Brgy. Cacafean, exposing the main fault, its splays, and placed stratigraphic units. Trench walls reveal eight to eleven sediment units and channel deposits which were delineated and described based on color, thickness, and sedimentological characteristics (e.g., texture, sorting, composition). Sediments are poorly consolidated and generally consist of muddy to silty sand, silty clay, and sandy gravels with angular to sub-rounded pebble- to cobble-sized clasts of igneous rocks sourced from the Ilocos Foothills. At least two faulting events that show normal displacement of stratigraphic horizons were interpreted based on paleo-earthquake indicators such as a) upward termination of the fault, b) thickening of deposits on the downthrown side of the fault, and c) downward increase in displacement. Transtensional movement of the ESBF is inferred based on its morphotectonic features and subsurface structure as revealed from paleoseismic trenching. The timing and recurrence of these faulting events will be constrained as radiocarbon ages become available.