Impact of historical and recent tsunamis on the coasts of southern Peru and northern Chile

津波

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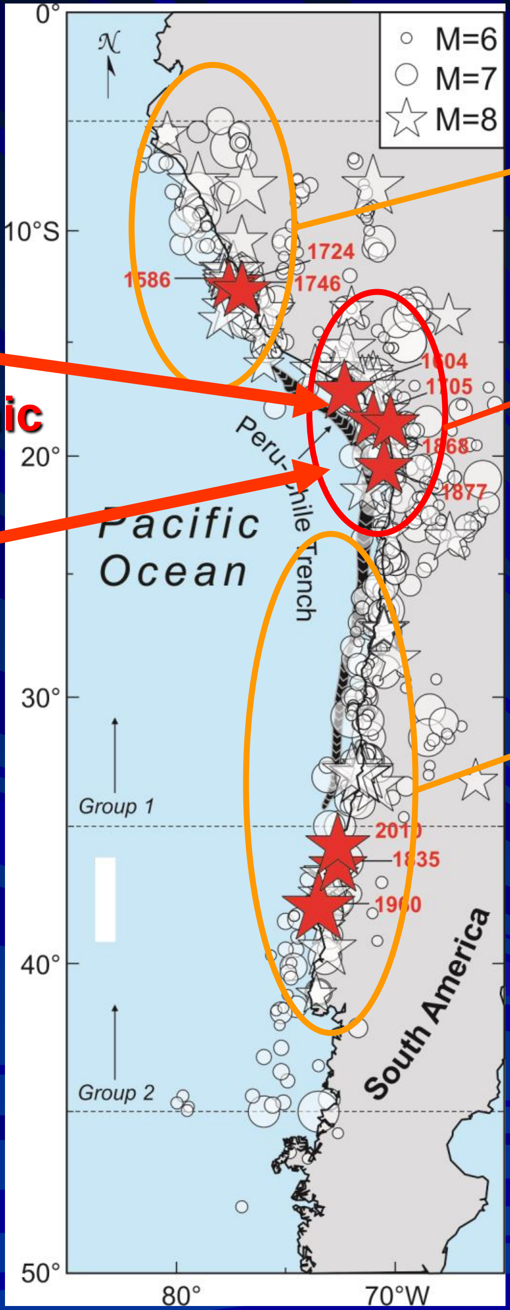
The coasts of Peru and Chile are characterized by one of the world's highest levels of seismicity and tsunami hazard…



Four types of tsunamis affecting southern Peru and northern Chile:

1. Local
2. Regional
3. Trans-oceanic
4. Non-seismic (landslide, volcanic, meterological)

Most important information sources

Askew, B., and T. Algermissen (Editors): 1985, Catalog of earthquakes for South America – hypocenter and intensity data, Earthquake Mitigation Program in the Andean Region, 7A, CERESIS, Lima, Peru, 190 pp.

*Berninghausen, W. H.: 1962, Tsunamis reported from the west coast of South America 1562-1960, Bull. Seismol. Soc. Amer., **52**(4), 915-921.*

Lockridge, P.A.: 1985, Tsunamis in Peru-Chile, World Data Center A for Solid Earth Geophysics, Report SE-39, U.S. Department of Commerce, NOAA, Boulder, CO. 97 pp.

*Lomnitz, C.: 1970, Major earthquakes and tsunamis in Chile during the period 1535 to 1955, Geolog. Rundsch., **59**(3), 938-960.*

Silgado, E.: 1985, Destructive Earthquakes of South America 1530-1894, Earthquake Mitigation Program in the Andean Region, 10, CERESIS, Lima, Peru, 328 p.

Soloviev, S.L., and Go, Ch.N.: 1975, Catalogue of Tsunamis on the Eastern Shore of the Pacific Ocean, Nauka Publ. House, Moscow, 204 pp. (in Russian; English translation: Canadian Transl. Fish. Aquatic Sci., No. 5078, Ottawa, 293 pp., 1984).

*(1) Tsunami Database of the National Geophysical Data Center for Natural Hazards (**NGDC**), Boulder, CO, USA*

*(2) Expert Tsunami Database for the Pacific (**ETDB**/PAC), Novosibirsk, RUSSIA*

Our old studies (1999-2005)…

2001

Tsunami risk estimation for the coasts of Peru and northern Chile

Alexander B. Rabinovich[1], Evgueni A. Kulikov[1], and Richard E. Thomson[2]

[1] *Tsunami Center, Shirshov Institute of Oceanology, Moscow, Russia*
[2] *Institute of Ocean Sciences, Sidney, British Columbia, Canada*

Abstract. Data for all known tsunamigenic earthquakes and observed tsunami run-up are used to estimate tsunami risk for the coasts of Peru and northern Chile for zones bounded by 0° to 35°S latitude. Tsunamigenic earthquake estimates yield magnitudes of 8.1, 8.4, and 8.7 with corresponding recurrence periods of 50, 100, and 200 years, respectively. According to the "seismic gap" theory, there is a high likelihood of a strong earthquake in the region between 15°S and 24°S. Based on the tsunami run-up data, we expect tsunami wave heights of 13 m for a 50-year return period and 25 m for a 100-year return period. Sophisticated numerical modeling of possible tsunami events is important for estimation of local resonant effects and detailed tsunami-zoning of this region.

1. Introduction

Tsunamis are among the world's most destructive natural hazards. To mitigate the loss of life and property, the possible impact of tsunami waves must be taken into account prior to major development or construction in seismically active regions of the ocean coast. The past 10 years (1992–2001) have been characterized by anomalously high tsunami activity in the World Ocean. The 17 major tsunamis recorded during this period—including the 21 February 1996 tsunami off Chimbote, northern Peru and the 17 July 1998 tsunami in Papua New Guinea—have been responsible for more than 4000 deaths and extensive property damage. The 1996 Chimbote tsunami was associated with the first large ($M_w > 7$) subduction-zone earthquake between 8 and 10°S in Peru since the 17th century. The devastating Papua New Guinea tsunami killed about 2200 villagers, including more than 230 children (González, 1999). Surprisingly, the large waves associated with the Papua New Guinea tsunami were generated by a relatively small earthquake ($M = 7.1$), indicating that destructive tsunami waves are not confined to earthquakes with extreme magnitudes.

Long-term tsunami prediction (tsunami-zoning) is of key importance to tsunami research, especially for areas of new coastal construction. Construction of complex and/or expensive structures in coastal areas requires reliable estimation of extreme tsunami run-up and run-down. Overestimation of the tsunami risk significantly increases the cost of construction, whereas underestimation of possible tsunami heights may have catastrophic consequences, including widespread destruction of property and loss of life. Tsunami-zoning involves the estimation of maximum tsunami heights, the corresponding inundation (or draw down), and the recurrence times for major tsunami events (cf. Mofjeld *et al.*, 1999).

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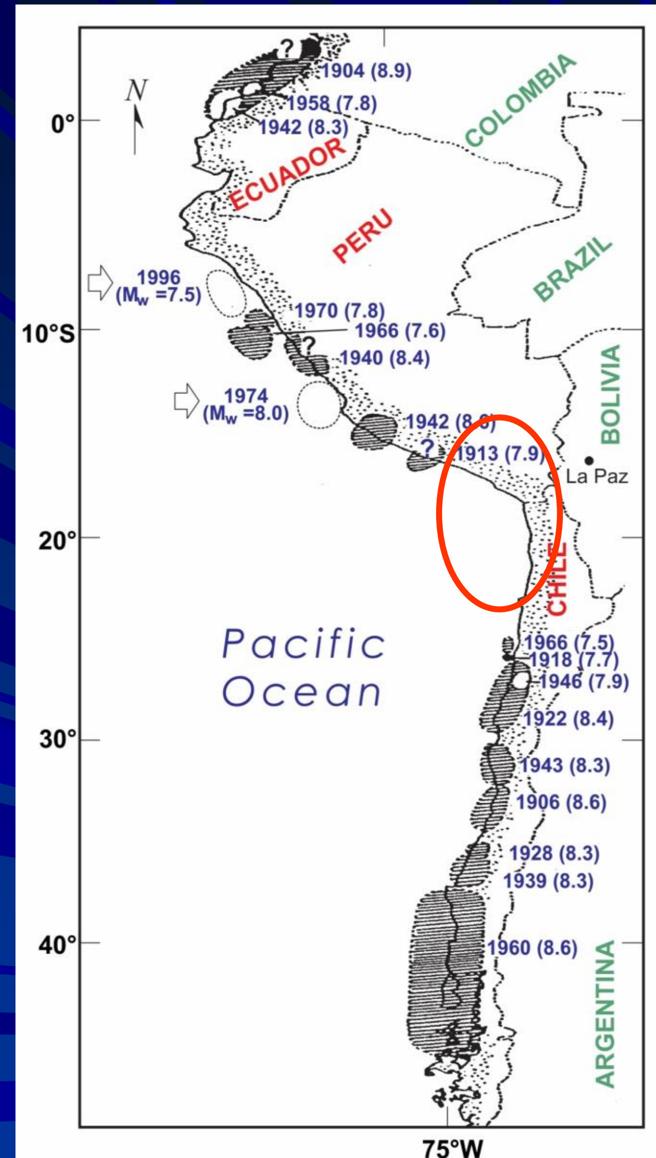
Rupture zones of large (*M*>7.5) S. American 20th century earthquakes



From Kelleher (1972)

Our old studies (1999-2005)…

2001

ITS 2001 PROCEEDINGS, SESSION 1, NUMBER 1-5 281

Tsunami risk estimation for the coasts of Peru and northern Chile

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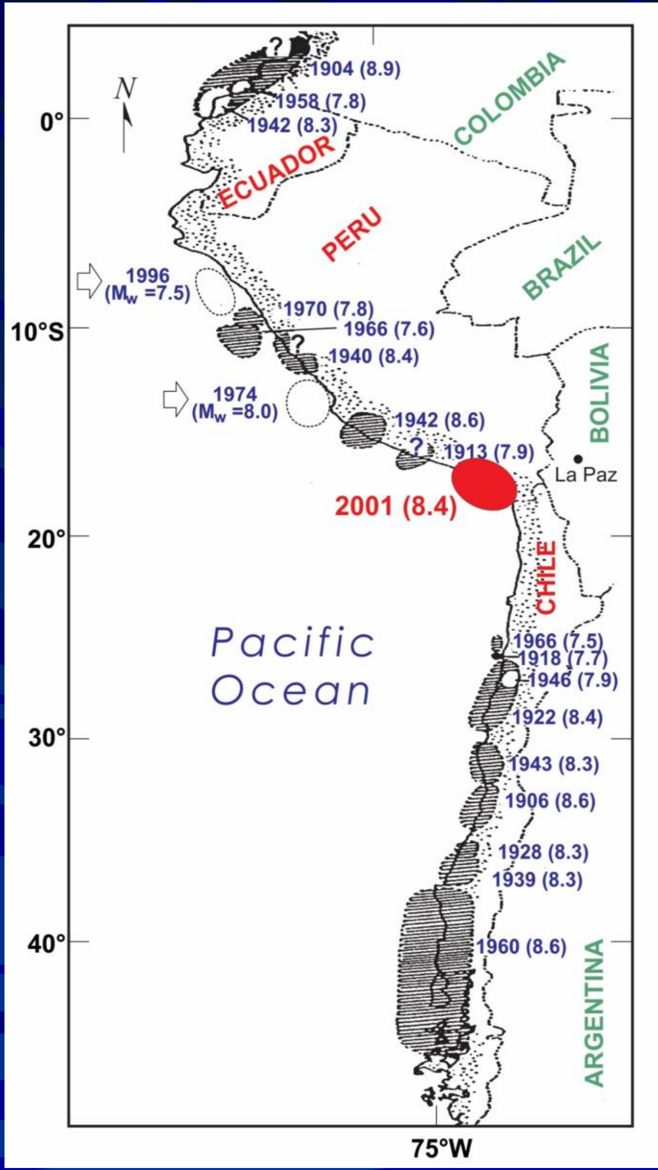

From Kelleher (1972)

Our old studies (1999-2005)…

2005 Natural Hazards

Natural Hazards (2005) 35: 185–209
DOI 10.1007/s11069-004-4809-3

Estimation of Tsunami Risk for the Coasts of Peru and Northern Chile

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(Received: 18 February 2004; accepted: 10 October 2004)

Abstract. Data for tsunamigenic earthquakes and observed tsunami run-up are used to estimate tsunami-risk for the coasts of Peru and northern Chile for zones bounded by 5–35° S latitude. Tsunamigenic earthquake estimates yield magnitudes of 8.52, 8.64, and 8.73 for recurrence periods of 50, 100, and 200 years, respectively. Based on three different empirical relations between earthquake magnitudes and tsunamis, we estimate expected tsunami wave heights for various return periods. The average heights were 11.2 m (50 years), 13.7 m (100 years), and 15.9 m (200 years), while the maximum height values (obtained by Iida's method) were: 13.9, 17.3, and 20.4 m, respectively. Both the "averaged" and "maximum" seismological estimates of tsunami wave heights for this region are significantly smaller than the actually observed tsunami run-up of 24–28 m, for the major events of 1586, 1724, 1746, 1835, and 1877. Based directly on tsunami run-up data, we estimate tsunami wave heights of 13 m for a 50-year return period and 25 m for a 100-year return period. According to the "seismic gap" theory, we can expect that the next strong earthquake and tsunami will occur between 19 and 28° S in the vicinity of northern Chile.

Key words: tsunami risk, tsunami wave height, return period, Peru, Chile, earthquake, seismic gap theory

1. Introduction

Tsunamis are among the world's most destructive natural hazards. To mitigate the loss of life and property, the possible impact of tsunami waves must be taken into account prior to major development or construction in seismically active regions of the ocean coast. The recent 12 years (1992–2003) have been characterized by anomalously high tsunami activity in the World Ocean. More than 20 catastrophic tsunamis occurred during this period, including the February 21, 1996 tsunami off Chimbote, northern Peru, the July 17, 1998 tsunami in Papua New Guinea, and the June 23, 2001 tsunami off the Camana–Chala region, Southern Peru. These tsunamis were

2005 Oceanology

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MARINE PHYSICS

On Long-Term Tsunami Forecasting

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[2] *Institute of Ocean Sciences, Sidney, British Columbia, Canada*
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Abstract Data for tsunamigenous earthquakes and tsunami events from the Expert Tsunami Database for the Paci c (ETDB) and from the Tsunami Database of the National Geophysical Data Center (NGDC) are used for long-term tsunami forecasting and for the determination of tsunami run-up distribution functions. The comparative analysis is exempli ed using the data for the Paci c coast of South America from 5° to 35° S (adjacent to Peru and northern Chile). The calculated recurrence periods and tsunami wave heights from the corresponding data were compared with each other and with the estimations from other independent sources. A stochastic model with a lognormal alongshore tsunami run-up distribution was found to be quite ef cient for the region under study. Based on the ETDB data, we expect tsunami wave heights of 2.7, 5.1, 10.2, and 16.3 m for 10-, 20-, 50-, and 100-year periods, while, from the NGDC data, we obtained 3.0, 5.7, 13.3, and 25.3 m wave heights, respectively. The signi cant differences in the results arise from the differences in the two datasets.

1. INTRODUCTION

Tsunamis are among the most dangerous natural phenomena. These catastrophic waves, which are usually formed as the result of strong underwater earthquakes, are most frequently observed at the coasts of the Paci c Ocean. The period from 1992 to 2003 was characterized by an unusually high number of destructive tsunamis, more than 20, including the tsunamis on July 12, 1993, in the Sea of Japan; October 4, 1994, near Shikotan Island (Kuril Islands); July 17, 1998, on the coast of Papua New Guinea; and June 23, 2001, on the southern coast of Peru. These tsunamis caused enormous economic damage and killed more than 4000 people.

The problem of long-term tsunami forecasting is especially important for the populated part of the Paci c coasts of Japan, Russia, the United States, Indonesia, and South America. Statistical analysis of the data for historical earthquakes and tsunamis allows us to estimate the degree of danger and risk related to the constructions on the coast and other types of economic and life activities. The calculation of the probability of earthquakes and tsunamis of certain force on a given interval of the coast is usually presented in the form of recurrence graphs. The standard periods of recurrence characterize not only the frequency of rare extreme events (with recurrence of 50, 100, and 200 years) but also the frequency of moderate events with periods of recurrence equal to 5, 10, and 20 years. Actually, the planning of economic activity and any new construction in seismically active and tsunami risk zones of the Paci c coast requires preliminary estimates of the possible oodings related to tsunamis.

The main problem in the analysis of the statistics of tsunamigenous earthquakes and tsunami heights is the completeness and quality of the data. The data coverage of the coast is directly related to its population and the availability of sea level recorders; over signi cant intervals of the coastline, the data of the ooding are absent. One has to take into account that systematic data gathering about powerful marine events is usually the most important issue in the estimates of extreme ooding. On the other hand, the historical evidence contains the data referring only to the strongest events, whose recurrence is most important for the assessment of extreme oodings. In order to estimate tsunami risks, it is necessary to correctly combine the comparatively complete statistics of tsunamis in 1900 2003 (including weak events) with the fragmentary historical information about catastrophic oodings on the coast in the previous period.

In this study, we discuss the problem of the probability description of the tsunami hazard based on the statistical analysis of historical data and tsunami heights. The requirement of the statistical reliability of the estimates obtained as a result of such an analysis frequently contradicts with the necessity of local forecasts for relatively small regions of the coast. Even in the regions with comparatively dense populations and the presence of observation networks, the number of tsunami records at each speci c point is small. However, for selected tsunami hazard zones, it is possible to distinguish segments with a relatively uniform distribution of tsunami recurrence along the coast. In this case, it is possible to form a representative data sample about the tsunami heights for the corresponding part of the coast. However, in this case, the statistical conclusions have a regional character. The calculated values of the probability are related to the entire interval of the coast considered. This means that the event with the given probability would occur somewhere in the study region of the coastline. In order to pass from the probability at

Tsunami Heights from Earthquake Magnitudes

Used relations:

Iida: $m = 2{:}61M + 18{:}44$, where $m = \log 2(h)$;

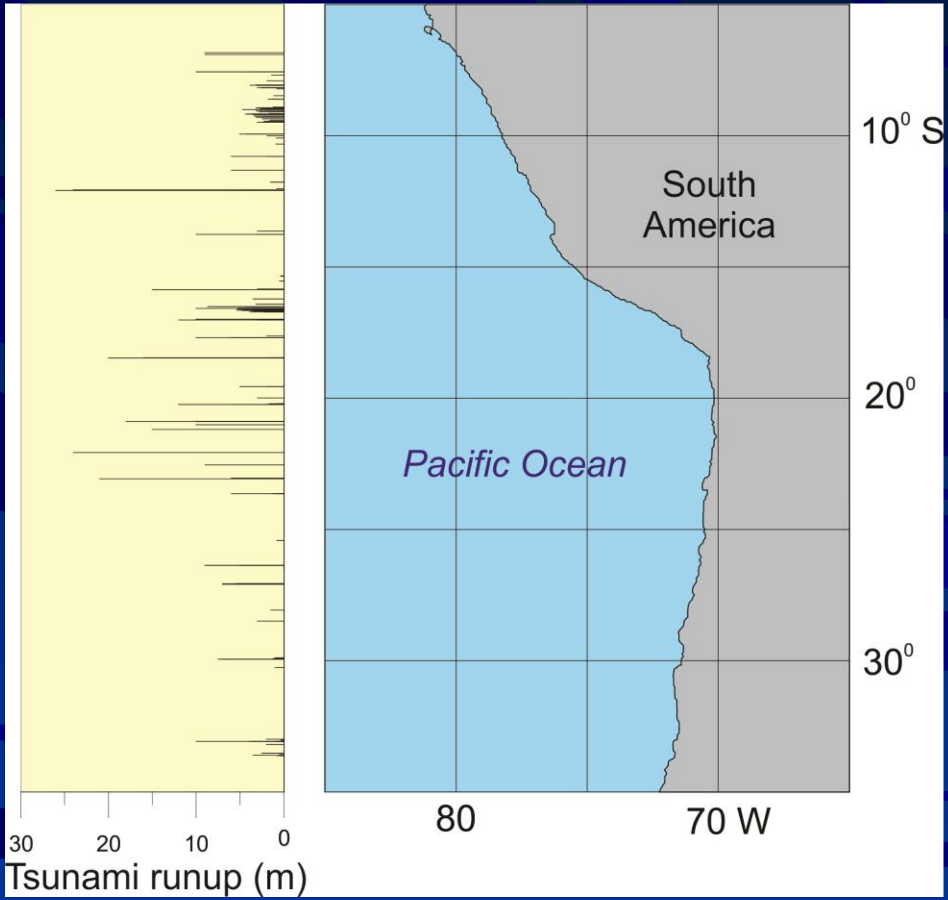
Abe: $\log(h) = 0.5M - 3.30$;

Silgado: $\log(h) = 0.79M - 5.70$;

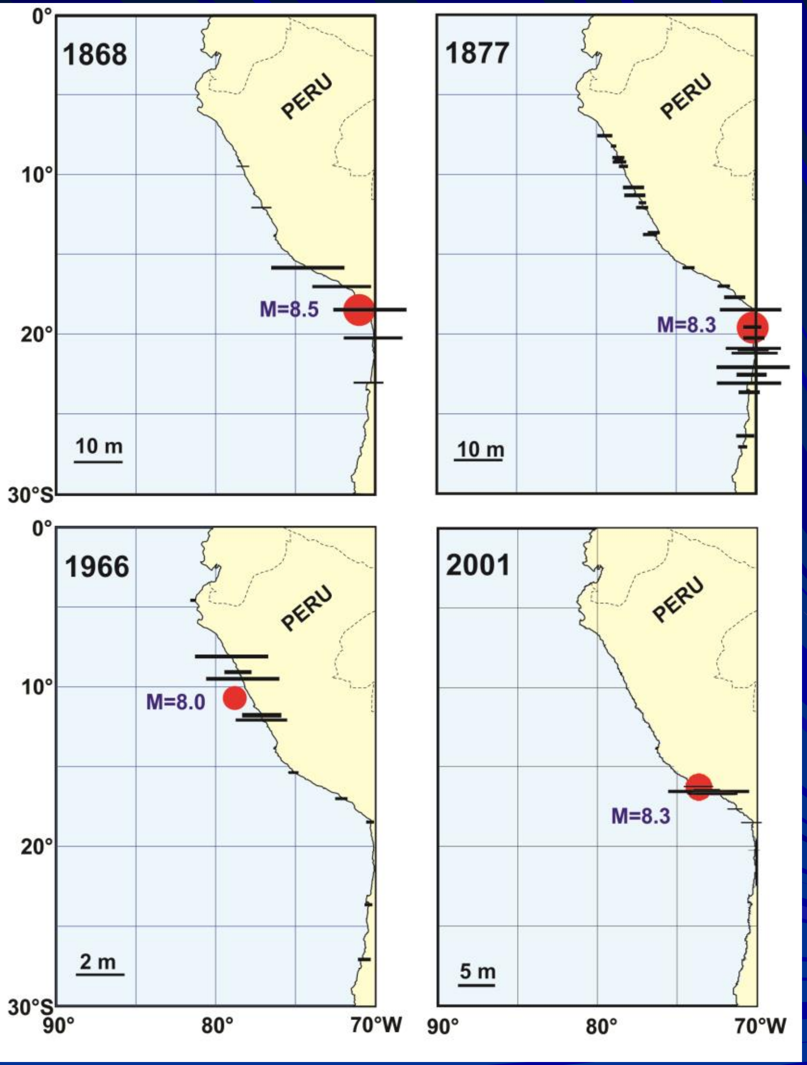
Tsunami wave heights (in meters) for different return periods estimated from earthquake magnitudes

Authors	Return period (years)						
	2	5	10	20	50	100	200
Iida	1.5	3.8	6.5	9.5	13.9	17.3	20.4
Abe	2.2	4.1	5.6	7.2	9.1	10.5	11.6
Silgado	1.2	3.1	5.0	7.3	10.7	13.4	15.7

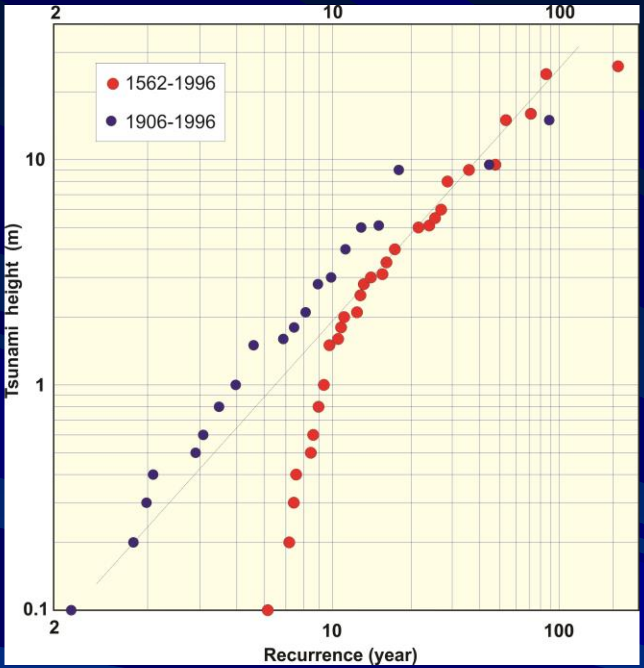
Maximum tsunami runup heights along the coasts of Peru and northern Chile (1562-2003)



Tsunami runup heights for four major evenets



Tsunami heights estimated from historical runup data



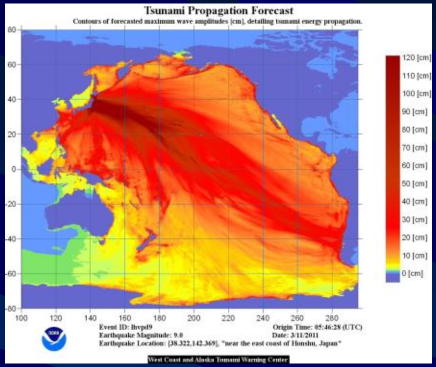
Two different observational periods

Observational period	Return periods, T_t (years)					
	5	10	20	50	100	200
1562-2003	-	1.4	4.9	13.4	24.1	40.0
2001-2003	1.0	2.9	6.3	14.4	25.0	40.0

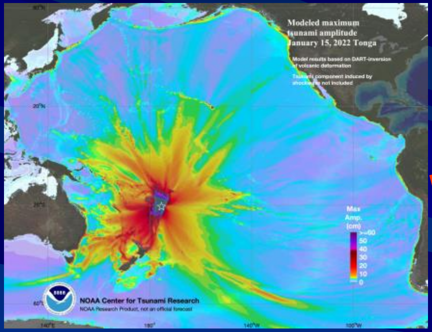
Two different tsunami data bases

Source	Return period (years)					
	5	10	20	50	100	200
HTDB (1575-2001)	1.3	2.7	5.1	10.2	16.3	24.9
NGDC (1901-2001)	1.3	3.0	5.7	13.3	25.3	-

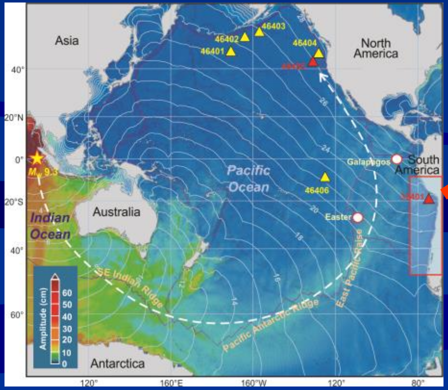
Recent tsunami events



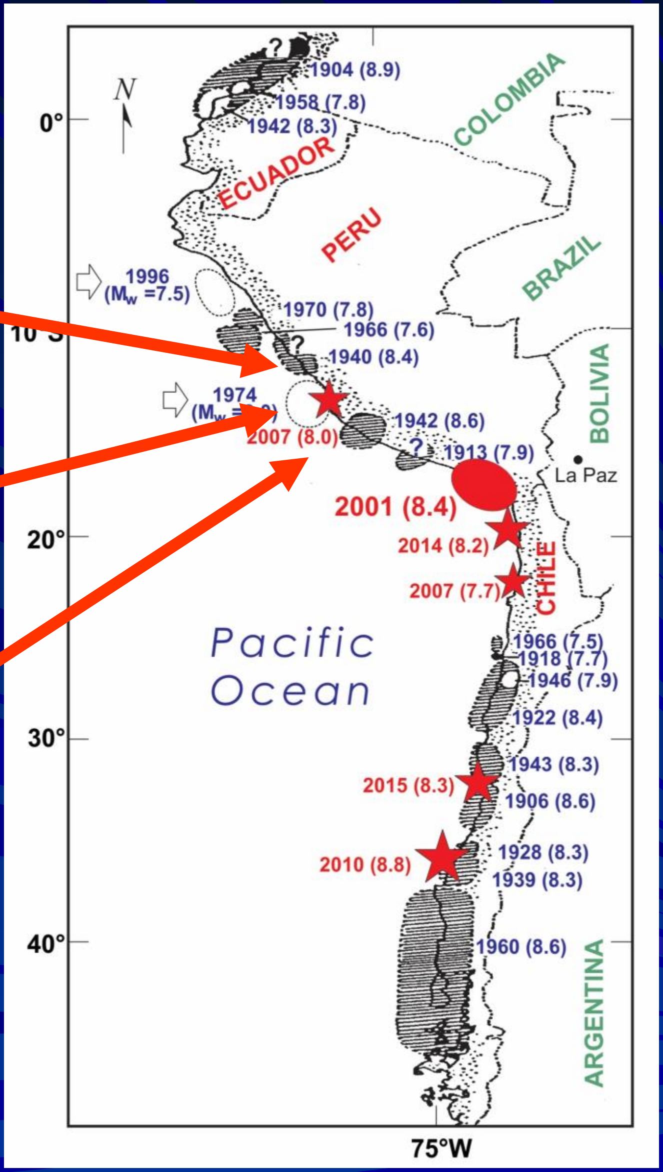
Tohoku 2011



Tonga 2022

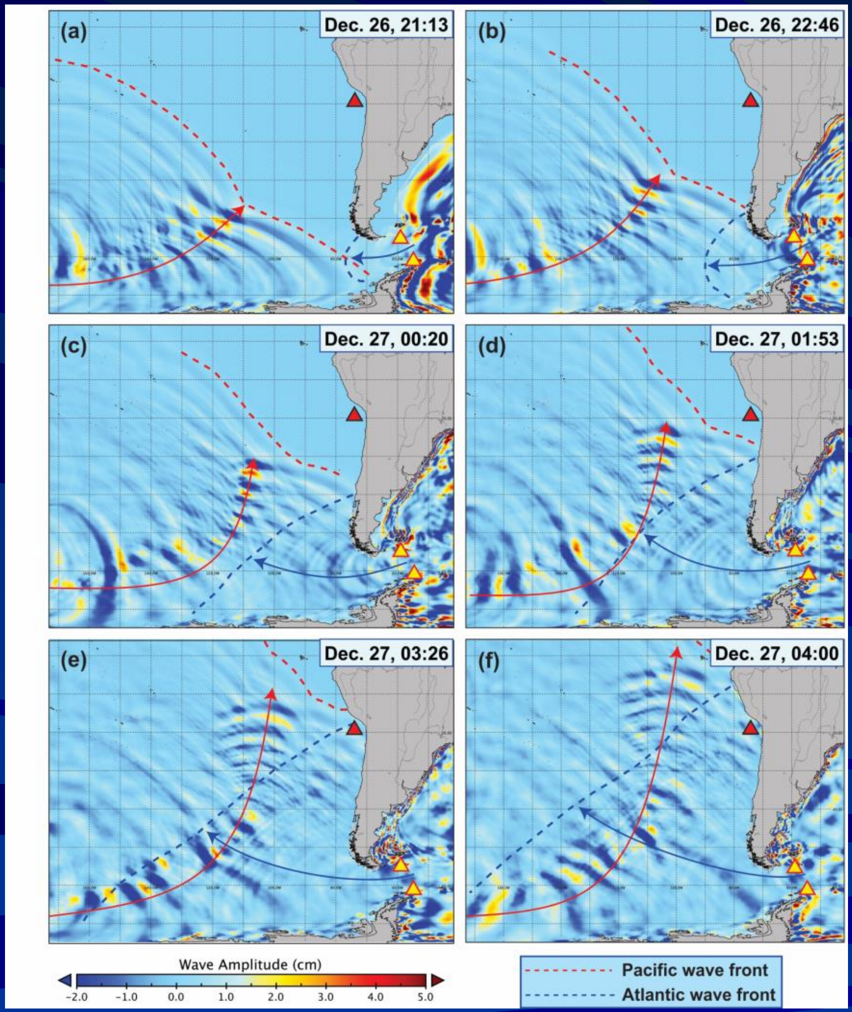


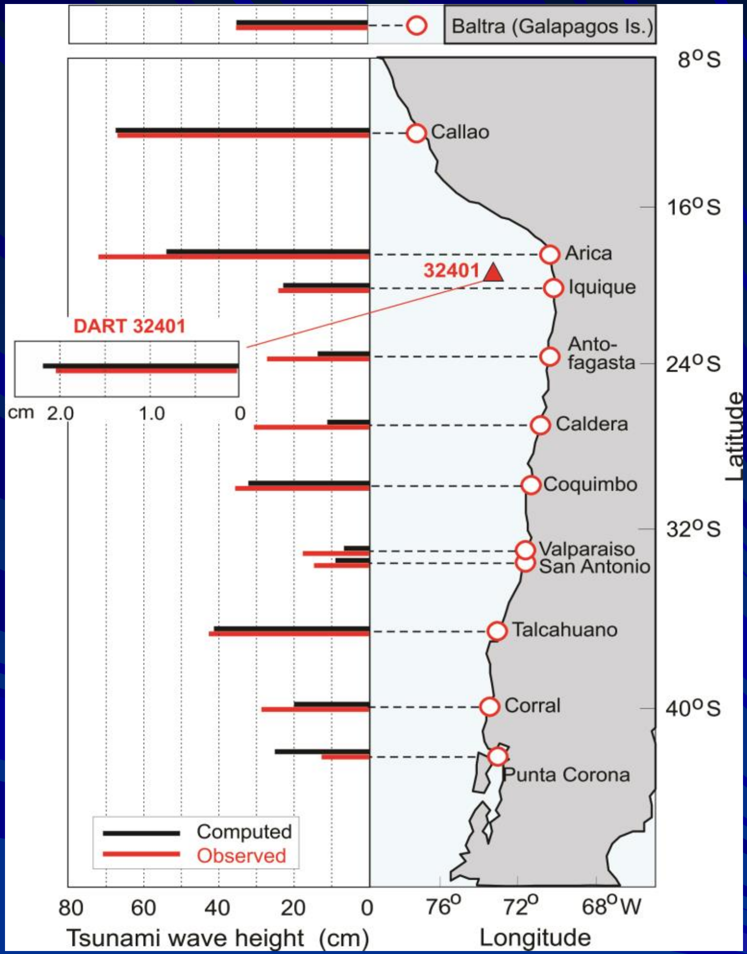
Sumatra 2004



Sumatra 2004: Observations and numerical modlling

"Pacific" and "Atlantic" wave convergence

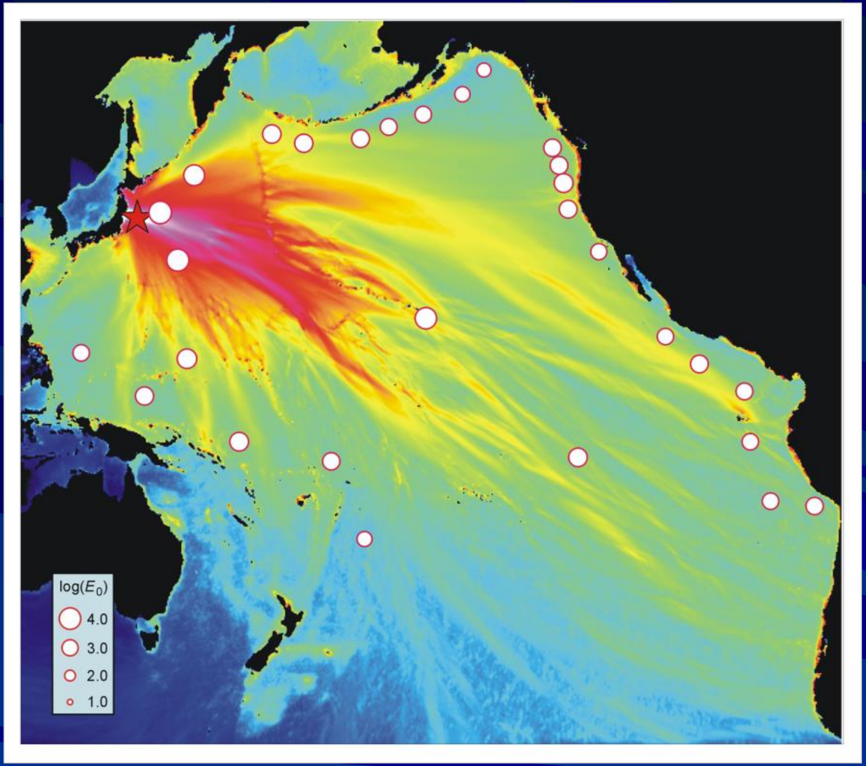




Max wave heights:
Callao 67 cm; Arica 72 cm

From *Rabinovich, Titov et al*. (JGR, 2017)

Tohoku 2011



Max wave amplitudes:

Baltra (Galapagos,

Ecuador) – 88 cm

Santa Cruz (Galapagos,

Ecuador) – 208 cm

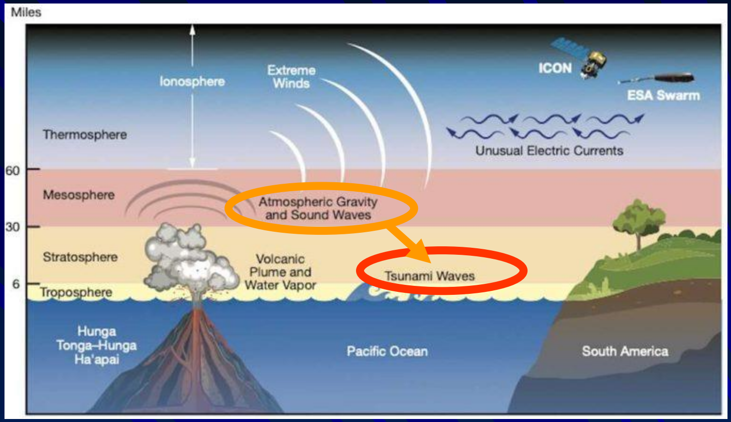
La Libertad (Ecuador) – 176 cm

Callao (Peru) -173 cm

Arica (Chile) - 250 cm

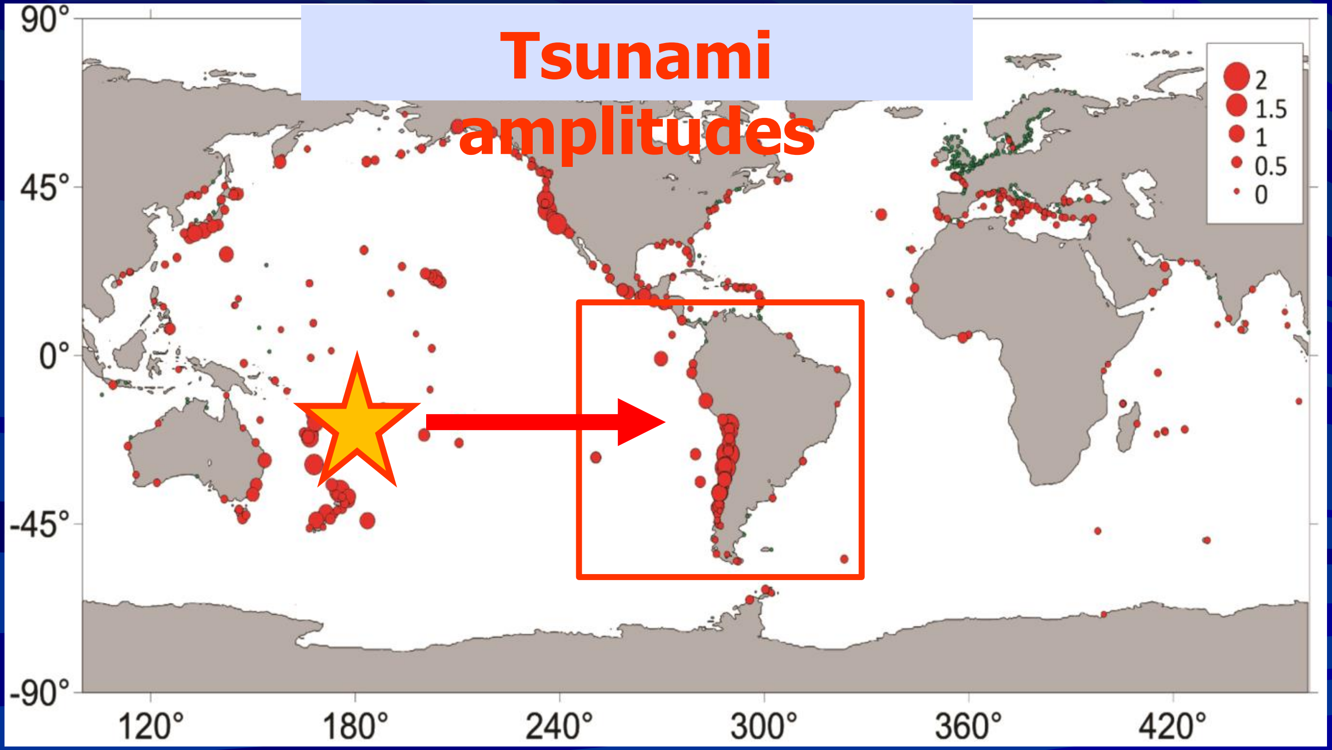
Caldera (Chile) – 201 cm

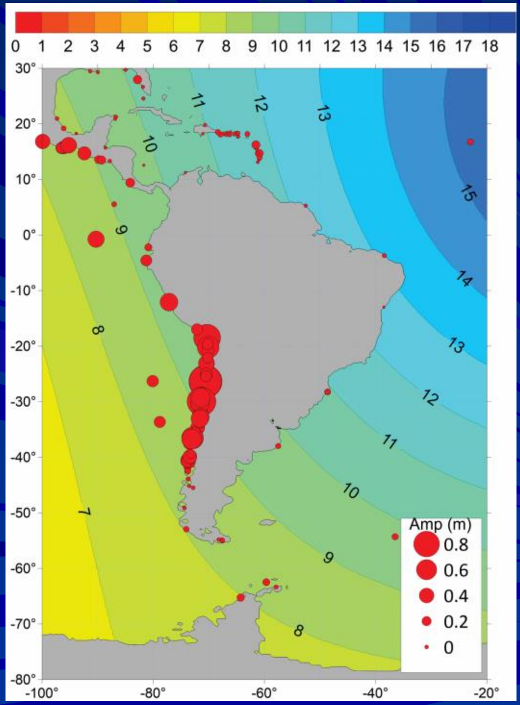
2022 Tonga tsunami



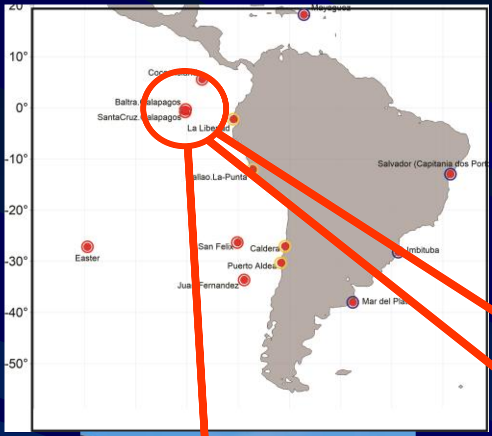
The coast of South America

Tsunami amplitudes



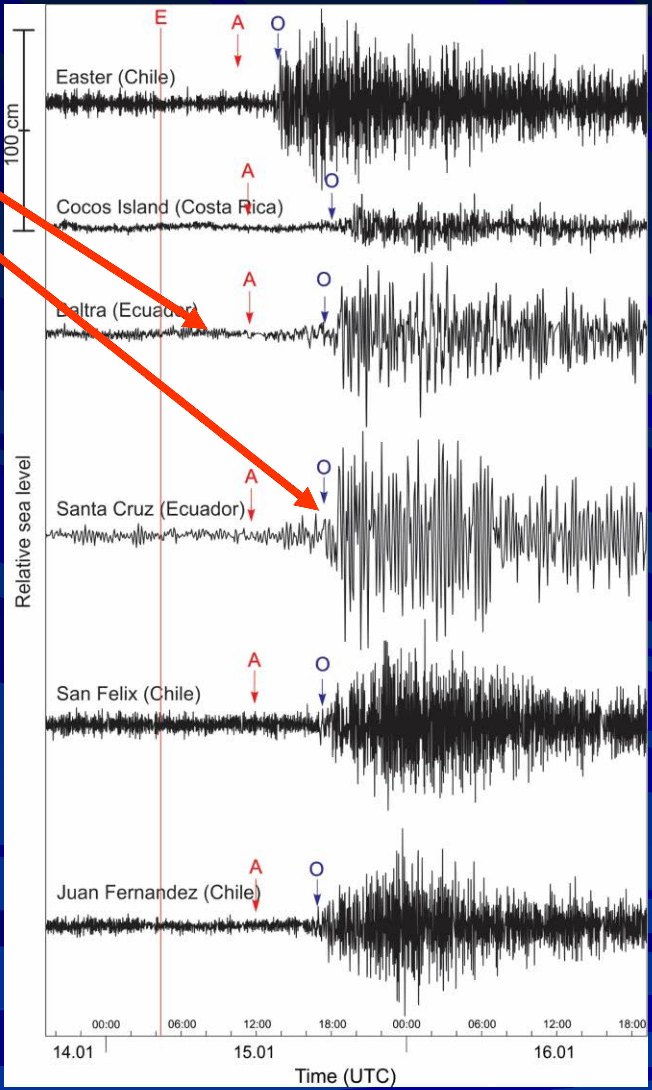


The 2022 Tonga tsunami recorded at and near the coast of South America

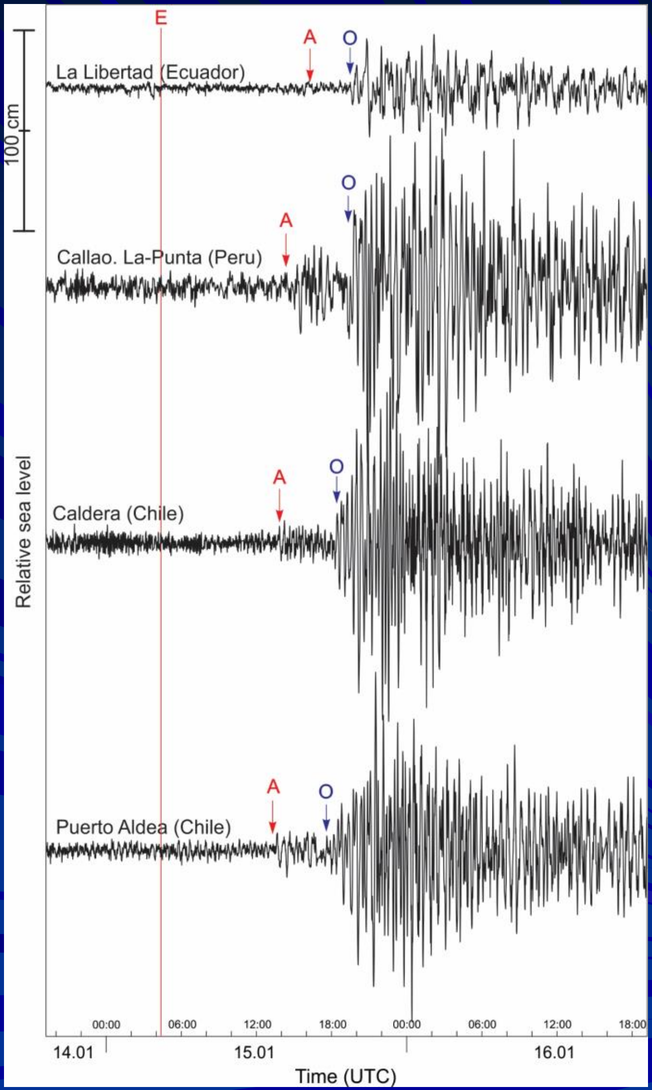


Tsunami sign: Isabela I., Galapagos

Island stations



Mainland SA stations



Thank you!

Any questions?