

Reconstructing and simulating past climate variability. The Mediterranean

J. Fidel González Rouco.

PalMA Res. Group.

Dpto. Astrofísica y CC. de la Atmósfera.

Universidad Complutense de Madrid. Spain

fidelgr@fis.ucm.es

The last decades have witnessed an important growth in research efforts and resulting knowledge regarding the evolution of climate during the last millennium. This has been parallel to an increasing concern about the rising global and hemispherical temperatures and has offered important insights into present and future climate (e. g. Houghton, 2005; Solomon et al. 2007). This area of paleoclimate research has helped not only to place the relatively short instrumental record into a broader temporal context (e. g. Jones and Mann 2004; North et al. 2006; Mann et al 2008) but also to explore the mechanisms behind climate events and periods that have been the subject of longstanding scientific interest like the Late Maunder Minimum within the little Ice Age or the Medieval Warm period (e. g. Shindell et al. 2001; Zorita et al 2004). Such insight into pre-instrumental variability has come both from climate reconstruction exercises using indirect (proxy) sources of information and from simulation of past climate states with General Circulation Models (GCMs). Exercises blending both approaches are still scarce and present a great potential for answering questions relevant both for the simulation and reconstruction of past climate and depend of the specific peculiarities of proxies and methods involved in climate reconstructions, as well as on the realism and limitations of model simulations. This talk explores both research lines with a focus on the Mediterranean climate variability along the last centuries.

Numerical simulation

Numerical simulation has used models of varying complexity, from energy balance models (EBM, e. g. Crowley 2000, Hegerl et al. 2006) and Earth system Models of Intermediate Complexity (EMIC, e. g. Goosse et al 2005, Bauer et al. 2006) to comprehensive atmosphere ocean GCMs (AOGCM, e.g. González-Rouco et al. 2003, Tett et al. 2007).

Efforts to simulate the last millennium with high temporal and spatial resolution have been limited by the extensive computer requirements. Nevertheless, the impressive evolution of computing power in the last several years has made it possible to accomplish multi-centennial and even millennial timescale simulations with comprehensive AOGCMs. Since these models are the ones that future climate projections rely on most heavily, evaluation of their performance in replicating aspects of climatic states different from the present is very important (e. g. Cane et al. 2006). Therefore, comparison of centennial to millennial simulations and reconstructions of the late Holocene climate offer the unique possibility of validating model simulations at long timescales before the onset of the industrial era and the beginning of heavy injection of greenhouse gases into the atmosphere. In addition, these simulations offer several other

research possibilities of relevance for the understanding of past climate and future climate change such as: analysis of the response to natural and anthropogenic external forcing and mechanisms involved (e. g. Cubasch et al. 1997, Goosse et al. 2006, Ammann et al 2007); comparison of model simulations and climate reconstructions to detect the signal of the various external forcing factors through the last millennium (e. g. Crowley, 2000; Hegerl et al. 2007) or to constrain estimates of climate sensitivity (Hegerl et al. 2006); use of model simulations as a surrogate reality in which *pseudo* proxies are built through the deterioration of simulations at the grid-point scale in order to test methods and assumptions relevant in proxy-based climate reconstructions (e. g. von Storch et al. 2004; Mann et al. 2005; González-Rouco et al 2006).

Climate reconstructions.

Climate reconstructions allow the history of climate parameters to be extended into the past before the advent of widespread instrumental records. Reconstructions are built from a variety of proxy indicators that include historical documentary records, tree-ring variables, ice-cores, corals, varved lake and marine sediments, speleothems, mollusc shells, etc. All these records can provide information at different temporal resolutions and with varying degrees of sensitivity to several climate parameters with an overall emphasis on temperature and precipitation (e. g. Jones et al. 1998). Climate reconstruction efforts have targeted a wide range of spatial scales: from the local and regional (e. g. Overpeck et al 1997; Luterbacher et al 2004) to hemispherical and global scales (e. g. Briffa et al 1998, Hegerl et al 2007, Mann et al. 2008). Though most efforts have been devoted to the reconstruction of past temperature variability, a great deal of research has also concentrated on reconstructing hydrological and atmospheric circulation indices (e. g. Luterbacher et al. 2002).

Hemispherical scale temperature reconstructions show general consistency in depicting broad climate periods through the last millennium (Jansen et al. 2007) like the Medieval Warm Period (MWP, centered around 1000 AD) or the Little Ice age (ca. 1500 to 1850 AD). Additionally hemispheric temperatures also decreased during events of shorter duration like the Late Maunder Minimum (LMM, ca. 1700 AD), the Spörer (SM ca. 1450 AD) or the Dalton Minimum (DM, ca 1800 AD) that are likely related to minima in solar activity. Nevertheless, quantitative agreement has been so far elusive and thus a matter of considerable debate in the last few years (see Jansen et al. 2007 and references therein).

The Mediterranean area offers a high quantity of long instrumental series and also a wealth of proxy records of high quality in a wide spectrum of sources from natural biological (e. g. trees, Guiot et al. 2005; corals, Silenzi et al. 2005) and geological (e. g. speleothems, Antonioli et al. 2003; sediments, Benito et al 2003) to documentary (e. g. Barriendos et al. 2002), many of which have so far only been initially surveyed. Available model multi-century simulations, though hampered by their limited resolution, are able to capture the main features of Mediterranean climate and can be used to compare and infer about past reality. This talk will address the main concepts behind the modelling and reconstruction approaches and present challenges in blending the potential of

both lines of work with an emphasis on the larger Mediterranean area. For a large overview on these issues with a detailed account on proxy type and availability the reader is addressed to the review by Luterbacher et al. (2006).

References

- Ammann, C. M., F. Joos, D. S. Schimel, B. L. Otto-Bliesner, and R. A. Tomas, 2007: Solar influence on climate during the past millennium: Results from transient simulations with the NCAR Climate System Model, *Proc. Nat. Acad. Sci.*, **104**, 3713-3718, doi:10.1073-pnas.0605064103.
- Antonioli, F., G. Cremona, F. Immordino, C. Puglisi, C. Romagnoli, S. Silenzi, E. Valpreda and V. Verrubbi, 2002: New data on the holocenic sea level rise in NW Sicily (Central Mediterranean Sea). *Glob. Planet. Change*, 716, 121-140.
- Barriendos, M., J. Martín-Vide, J. C. Pena and R. Rodríguez, 2002: Daily meteorological observations in Cadiz – San Fernando. Analysis of the documentary sources and the instrumental data content (1786-1996). *Climate Change*, **53**, 151-170.
- Benito, G., A. Díez-Herrero and M. Fernández de Villalta, 2003: Magnitude and frequency of flooding in the Tagus basin (Central Spain) over the last millennium, *Climate Change*, 58, 171-192.
- Briffa, K. R., P. D. Jones, F. H. Schweingruber, and T. J. Osborn, 1998a: Influence of volcanic eruptions on Northern Hemisphere summer temperature over the past 600 years, *Nature*, **393**, 450-454.
- Cane, M. A., P. Braconnot, A. Clement, H. Gildor, S. Joussaume, M. Kageyama, M. Khodri, D. Paillard, S. Tett, and E. Zorita, 2006: Progress in paleoclimate modeling, *J. Clim.*, **19**, 5031-5057.
- Crowley, T. J., 2000: Causes of climate change over the past 1000 years, *Science*, **289**, 270-277.
- Cubasch, U., R. Voss, G. C. Hegerl, J. Waszkewitz, and T. J. Crowley, 1997: Simulation of the influence of solar radiation variations on the global climate with an ocean-atmosphere general circulation model, *Clim. Dyn.*, **13**, 757-767.
- González-Rouco, J. F., H. von Storch, and E. Zorita, 2003: Deep soil temperature as proxy for surface air-temperature in a coupled model simulation of the last thousand years, *Geophys. Res. Lett.*, **30**, 2116-2119.
- González-Rouco, J. F., H. Beltrami, E. Zorita, and H. von Storch, 2006: Simulation and inversion of borehole temperature profiles in surrogate climates: Spatial distribution and surface coupling, *Geophys. Res. Lett.*, **33**, L01703, doi:10.1029/2005GL024693.
- Goosse, H., T. J. Crowley, E. Zorita, C. M. Ammann, H. Renssen, and E. Driesschaert, 2005: Modelling the climate of the last millennium: what causes the differences between simulations?, *Geophys. Res. Lett.*, **32**, L06710.
- Goosse, H., O. Arzel, J. Luterbacher, M. E. Mann, H. Renssen, N. Riedwyl, A. Timmermann, E. Xoplaki, and H. Wanner, 2006a: The origin of the European 'Medieval Warm Period', *Clim Past*, **2**, 99-113.

- Guiot, J., A. Nicault, C. Rathgeber, J. L. Edouard, F. Guibal, G. Pichard and C. Till, 2005: Last-millennium summer-temperature variations in Western Europe based on proxy data. *Holocene*, **15**, 489, doi: 10.1191/0959683605h1819rp.
- Hegerl, G. C., T. J. Crowley, W. T. Hyde, and D. J. Frame, 2006: Climate sensitivity constrained by temperature reconstructions over the past seven centuries, *Nature*, **440**, 1029-1032.
- Hegerl, G. C., T. J. Crowley, M. Allen, W. T. Hyde, H. N. Pollack, and J. S. E. Zorita, 2007: Detection of human influence on a new, validated 1500 year temperature reconstruction, *J. Clim.*, **20**, 650-666.
- Jansen, E., J. Overpeck, K. R. Briffa, J. C. Duplessy, V. Masson-Delmotte, D. Olago, B. Otto-Bliesner, W. R. Peltier, S. Rahmstorf, R. Ramesh, D. Raynaud, D. Rind, O. Solomina, R. Villalba, and D. Zhang, 2007: *Paleoclimate. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [S. Solomon and D. Qin and M. Manning and Z. Chen and M. Marquis and K. B. Averyt and M. Tignor and H. L. Miller (eds.)]*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Jones, P. D., K. R. Briffa, T. P. Barnett, and S. F. B. Tett, 1998: High-resolution paleoclimatic records for the last millennium: interpretation, integration and comparison with General Circulation Model control-run temperatures, *The Holocene*, **8**, 455-471.
- Houghton, J., 2005: Global warming, *Rep. Prog. Phys.*, **68**, 1343-1403.
- Jones, P. D., and M. Mann, 2004: Climate over past millennia, *Rev. Geophys.*, **42**, 1-42 RG2002, doi: 10.1029/2003RG000143.
- Luterbacher, J., D. Dietrich, E. Xoplaki, M. Grosjean, and H. Wanner, 2004: European seasonal and annual temperature variability, trends and extremes since 1500, *Science*, **303**, 1499-1503.
- Luterbacher, J., E. Xoplaki, D. Dietrich, P. D. Jones, T. D. Davies, D. Portis, J. F. González-Rouco, H. von Storch, D. Gyalistras, C. Casty, and H. Wanner, 2002a: Extending North Atlantic Oscillation Reconstructions Back to 1500, *Atmos. Sci. Lett.*, **2**, 114-124.
- Luterbacher, J., and 48 coauthors, 2006: Mediterranean climate variability over the last centuries: A review, in: *The Mediterranean Climate: an overview of the main characteristics and issues*, Eds. Lionello, P., Malanotte-Rizzoli, P., and Boscolo, R., Elsevier, Amsterdam, the Netherlands, 27-148.
- Mann, M., Z. Zhang, M. K. Hughes, R. S. Bradley, S. K. Miller, S. Rutherford and F. Ni, 2008: Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia, *PNAS*, **105**, doi 10.1073_pnas.08055721105.
- Mann, M. E., S. Rutherford, E. Wahl, and C. Amman, 2005: Testing the fidelity of methods used in proxy-based reconstructions of past climate, *J. Climate*, **18**, 4097-4107.
- North, G. R., F. Biondi, P. Bloomfield, J. R. Christy, K. M. Cuffey, R. E. Dickinson, E. R. M. Druffel, D. Nychka, B. Otto-Bliesner, N. Roberts, K. K. Turekian, J. M. Wallace, I. Kraucunas, C. Elfring, A. Staudt, E. A. Galinis, L. Probst, D. Gustafson, and N. Grossblatt, 2006: *Surface temperature reconstructions for the last 2000 years*. Washington, D. C.: National Research Council. The National Academies Press, 92 pp.

- Overpeck, J., K. Hughen, D. Hardy, R. Bradley, R. Case, M. Douglas, B. Finney, K. Gajewski, G. Jacoby, A. Jennings, S. Lamoureux, A. Lasca, G. MacDonald, J. Moore, M. Retelle, S. Smith, A. Wolfe, and G. Zielinski, 1997: Arctic environmental change of the last four centuries, *Science*, **278**, 1251-1256.
- Shindell, D. T., G. A. Schmidt, M. E. Mann, D. Rind, and A. Waple, 2001: Solar forcing or regional climate change during the Maunder Minimum, *Nature*, **294**, 2149-2152.
- Silenzi, S., E. Bard, P. Montagna and F. Antonioli, 2005: Isotopic and elemental records in a non-tropical coral (*Cladocora caespitosa*): discovery of a new high-resolution climate archive for the Mediterranean Sea. *Global Planet. Change.*, **49**, 94-107.
- Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. M. (eds.), 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Tett, S. F. B., R. Betts, T. J. Crowley, J. Gergory, T. C. Johns, A. Jones, T. J. Osborn, E. Ostrom, D. L. Roberts, and M. J. Woodgate, 2007: The impact of natural and anthropogenic forcings on climate and hydrology since 1550, *Clim. Dyn.*, **28**, 3-34.
- von Storch, H., E. Zorita, Y. Dimitriev, F. Gonzalez-Rouco, and S. Tett, 2004: Reconstructing past climate from noisy data, *Science*, **306**, 679-682.
- Zorita, E., H. von Storch, J. F. González-Rouco, J. Luterbacher, U. Cubasch, S. Legutke and U. Schlese, 2004: Climate evolution in the last five centuries simulated by an atmosphere-ocean model: global temperatures, the North Atlantic Oscillation and the Late Maunder Minimum, *Met. Zeitsch.*, **13** 271-289.