

Activitats del CMIMA-CSIC en l'estudi de les relacions dels oceans amb el clima

Resum

El pla estratègic del Centre Mediterrani d'Investigacions Marines i Ambientals (CMIMA) estableix que una de les seves línies prioritàries de recerca és l'estudi del paper dels oceans en el canvi climàtic. La multidisciplinarietat del CMIMA (format per la Unitat de Tecnologia Marina i els departaments de Biologia Marina, Geologia, Oceanografia Física, i Recursos Marins Renovables de l'Institut de Ciències del Mar) es tradueix en una continua utilització de les dades obtingudes en campanyes oceanogràfiques, sèries temporals d'observació, i dades obtingudes a partir d'ancoratges, flotadors i satèl·lits amb l'objectiu de fer un seguiment de l'estat del mar i millorar el coneixement del paper dels oceans en l'evolució passada i present del clima. A més, es pretén comprendre i predir els efectes que el canvi climàtic tindrà en l'estructura i funcionament de les comunitats biològiques marines, la biodiversitat i la disponibilitat dels recursos renovables. Malgrat que l'activitat del CMIMA comprèn tot l'oceà, bona part de la recerca que s'hi fa està centrada en la conca mediterrània, especialment la regió nord-occidental.

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Introducció

Els oceans cobreixen gairebé el 70% de la superfície de la Terra de manera que més de dos terços de la radiació solar incideix en la superfície de l'oceà. Una petita part d'aquesta radiació es reflecteix (l'albedo dels oceans, 0.06, és un ordre de magnitud més petit que l'albedo del gel i dels núvols *estratus*) i la major part s'absorbeix. Malgrat que els oceans absorbeixen una fracció molt important de la radiació solar, això es tradueix en un canvi relativament petit de la seva temperatura degut al gran volum d'aigua que contenen i a la seva elevada calor específica (més del doble que les del gel i de l'aire). Des d'un punt de vista termodinàmic, els oceans juguen un paper fonamental en la regulació de la temperatura del planeta. La densitat de l'aigua és unes mil vegades més gran que la densitat de l'aire, cosa que incrementa la inèrcia dels oceans en front dels forçaments mecànics i provoca que els corrents oceànics siguin molt més lents que els corrents presents a l'atmosfera (vents), mostrant l'oceà una estratificació més estable. Els corrents oceànics transporten part de la calor emmagatzemada a la zona tropical cap a latituds més altes. D'altra banda la biota marina juga un paper important en el balanç de calor de les capes superficials de l'atmosfera i en els fluxos de CO₂ i altres substàncies amb implicació climàtica entre l'atmosfera i l'oceà. Les respostes dels oceans als diferents forçaments, així com a diverses retroaccions, s'estenen en un ampli rang d'escala temporal que va des dels pocs dies fins a milers d'anys. El coneixement de la dinàmica dels oceans a diverses escales és, doncs, important per entendre els canvis en el clima del passat, present i futur.

Des de l'any 1951, l'Institut de Ciències del Mar (ICM) del Consell Superior d'Investigacions Científiques (CSIC) ha tingut com a objectiu l'estudi de la biologia marina i, des de fa més de trenta anys, l'estudi multidisciplinar dels oceans. En el 2000, l'ICM va incorporar-se al CMIMA, que ha esdevingut el centre de recerca i desenvolupament en ciència i tecnologia marines més gran de tot l'Estat Espanyol amb prop de 200 investigadors (més de 60 en el Departament de Biologia marina, més de 40 en els departaments de Geologia i d'Oceanografia Física, 50 en el de Recursos Renovables, i més de 40 a la Unitat de Tecnologia Marina). El CMIMA té un pressupost anual de 4.6M€ (any 2004). El pla estratègic del CMIMA per al període 2005-2009 estableix que un dels objectius de recerca és l'estudi del paper dels oceans en el canvi climàtic. Durant aquest període, aquest objectiu s'acompleix a través de les Línies de Recerca del centre: i) l'estructura i dinàmica oceànica a diferents escales; ii) l'estudi dels sediments en el marge continental; iii) l'estudi dels fluxos de matèria i energia en els oceans; iv) la biodiversitat i dinàmica dels ecosistemes marins; v) l'estudi de les poblacions i espècies marines; vi) la recerca integrada del sistema costaner; i vii) la sostenibilitat dels recursos marins. Per dur a terme les tasques de recerca, el CMIMA compta amb serveis d'anàlisi, de documentació, un sistema informàtic propi (300 nodes actius i 350 ordinadors personals) que està directament connectat a la xarxa catalana de recerca acadèmica (CESCA), Disposa de 1580 m² d'espai per a despatxos i 4318 m² d'espai de laboratori i altres espais de recerca. El CMIMA edita la revista *Scientia Marina*, l'única revista espanyola de ciències marines inclosa en el Science Citation Index.

L'àmbit d'estudis natural del CMIMA és el Mar Mediterrani, però no és, ni molt menys, l'exclusiu. De fet, els investigadors del CMIMA han dut i duen projectes de recerca arreu del món, de l'Antàrtic a l'Àrtic passant per les regions subtropicals de l'Atlàntic i el Pacífic, els afloraments africans, l'Oceà Austral i els mars continentals nord-europeus. Tanmateix, el Mediterrani occidental és sens dubte la conca que ha estat més profusament estudiada a partir de l'obtenció de dades *in-situ* i mitjançant models numèrics. Un dels aspectes interessants del Mar Mediterrani és que, degut a la seva profunditat i dinàmica, funciona com un gir oceànic a escala menor, i molts dels processos d'importància en la circulació i la biologia dels oceans globals es poden observar també en el Mediterrani. Per exemple, la

circulació forçada pels vents, la formació d'aigües profundes, els efectes dels rius en la circulació, les inestabilitats associades a estructures de mesoescala, l'existència d'un esquema de circulació tridimensional que ocupa tota la conca, una clara estacionalitat en la producció i diversitat planctòniques com a resposta al cicle d'estratificació i barreja, l'alternança de xarxes tròfiques planctòniques, la formació de màxims profunds de biomassa, l'existència de costes i talussos submarins amb comunitats bentòniques molt riques, l'entrada i establiment d'espècies invasores, una gran pressió pesquera, la resposta de la distribució de les poblacions de fauna als canvis ambientals, el transport de sediments al llarg de talussos molt accentuats. El Mediterrani, doncs, a més d'interessar per la seva especificitat, ofereix un model abastable per a l'estudi de les interrelacions entre l'oceà, el clima i l'activitat humana.

1. Recerca per a la caracterització de la variabilitat anual i interanual en la física oceànica

Bona part de les publicacions dels investigadors de l'ICM-CMIMA estan relacionades amb la caracterització de la circulació i variabilitat del Mar Mediterrani i de l'Oceà Atlàntic. D'entre elles, una part important es refereix a variables clau en l'acoblament directe entre els oceans i l'atmosfera com, per exemple, la temperatura de superfície (SST), el contingut de calor de les aigües oceàniques que comporta variacions de nivell (efecte estèric), o l'evolució de les masses d'aigua profunda. En particular, la circulació termohalina del mar Mediterrani integra els diferents forçaments (atmosfèrics i hídrics) de l'àmbit mediterrani per modular les aigües profundes i intermèdies i, per tant, els intercanvis amb el l'oceà Atlàntic. Cal destacar la variabilitat interanual del transport d'aigua en alguns dels estrets de la conca mediterrània i de la seva correlació amb fluctuacions de baixa freqüència de l'Oscil·lació de l'Atlàntic Nord (NAO) que indiquen l'existència d'un pont entre fluctuacions atmosfèriques de gran escala i la circulació d'aigües profundes a la conca mediterrània (Figura 1).

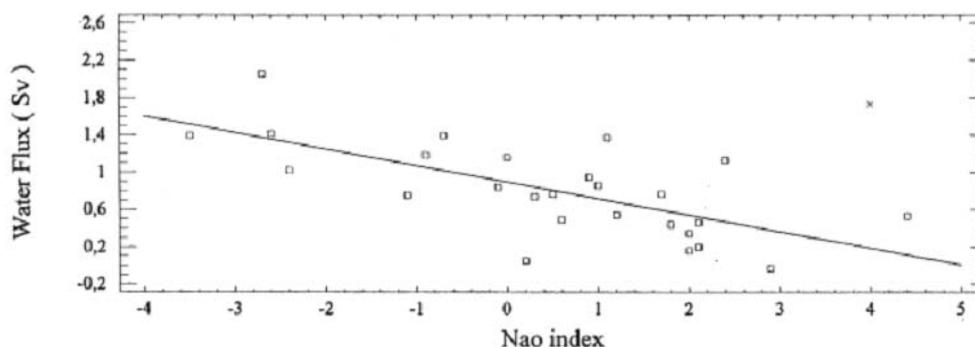


Figura 1: Regressió lineal entre la mitjana mensual del transport en el canal de Corsega i l'índex NAO des de 1985 al 1996 (Astraldi et al., 1999). Tot i que els intercanvis d'aigües entre les diferents sub-conques mediterrànies estan principalment regulats per les seves característiques hidrogràfiques lligades a la variabilitat estacional, en algunes zones hi ha una forta modulació interanual que evidencia el paper de components climàtiques com els balanços en els fluxes superficials de calor.

Projectes amb objectius de variabilitat anual i interanual de la física oceànica

- **Campaña Oceanográfica del proyecto Corriente de Afloramiento del Noroeste Africano (CO-CANOA)** (CTM2006-26238-E/MAR)
Finançament: Ministerio de Educación y Ciencia,
Investigador Principal: J. L. Pelegrí
Durada: 2007
- **Corriente de Afloramiento del Noroeste Africano (CANOA)** (CTM2005-00444/MAR)
Finançament: Ministerio de Educación y Ciencia
Investigador Principal: J. L. Pelegrí
Durada: 2005-2008
- **Capa límite de fondo oceánica: estructura, dinámica e intercambio de propiedades con el océano interior**
Finançament: Ministerio de Educación, Cultura y Deportes
Investigador Principal: J. L. Pelegrí
Durada: 2002-2003.
- **Estructura y variabilidad de la corriente, temperatura y sedimentos sobre taludes: procesos físicos, mediciones convencionales y mediciones mediante cables submarinos telefónicos (TALUD)**
Finançament: Comisión Interministerial de Ciencia y Tecnología,
Investigador Principal: J. L. Pelegrí
Durada: 1997-1999
- **Mediciones durante el tránsito del BIO Hespérides entre Cartagena y Las Palmas en Otoño de 1997**
Finançament: Comisión Interministerial de Ciencia y Tecnología
Investigador Principal: J. L. Pelegrí
Durada: 1997-1998
- **Ecohidrodynamical study of the Canary Islands marine system**
Finançament: Comisio Europea, Programa de Ciències i Tecnologies Marines,
Investigador Principal: J. L. Pelegrí
Durada: 1996-1997

2. Recerca en variabilitat climàtica

Sèries temporals d'observacions de la temperatura i salinitat en el Mar Mediterrani mostren que durant el segle XX hi ha hagut un augment de la temperatura i la salinitat (Figura 2). Algunes de les conseqüències d'aquests canvis poden ser: i) la modificació de les pautes de reproducció d'espècies marines i desplaçaments/substitucions de poblacions (p. ex., la *Sardinella aurita*); ii) l'avançament de les condicions d'estiu en el calendari (0.56 dies/any); iii) la disminució de l'evaporació; iv) la disminució de la precipitació en el període Abril-Juny (amb les corresponents repercussions a diversos sectors de l'economia); v) el canvi de masses d'aigua en el Mediterrani amb conseqüències en els

intercanvis a través de l'estret de Gibraltar i en la circulació d'aigües intermèdies a l'oceà Atlàntic.

Projectes de recerca sobre variabilitat climàtica

- **Hydro-Changes: Tracking hydrographic changes in the Mediterranean Sea. CIESM**
Coordinador: C. Millot
Durada: 2002-

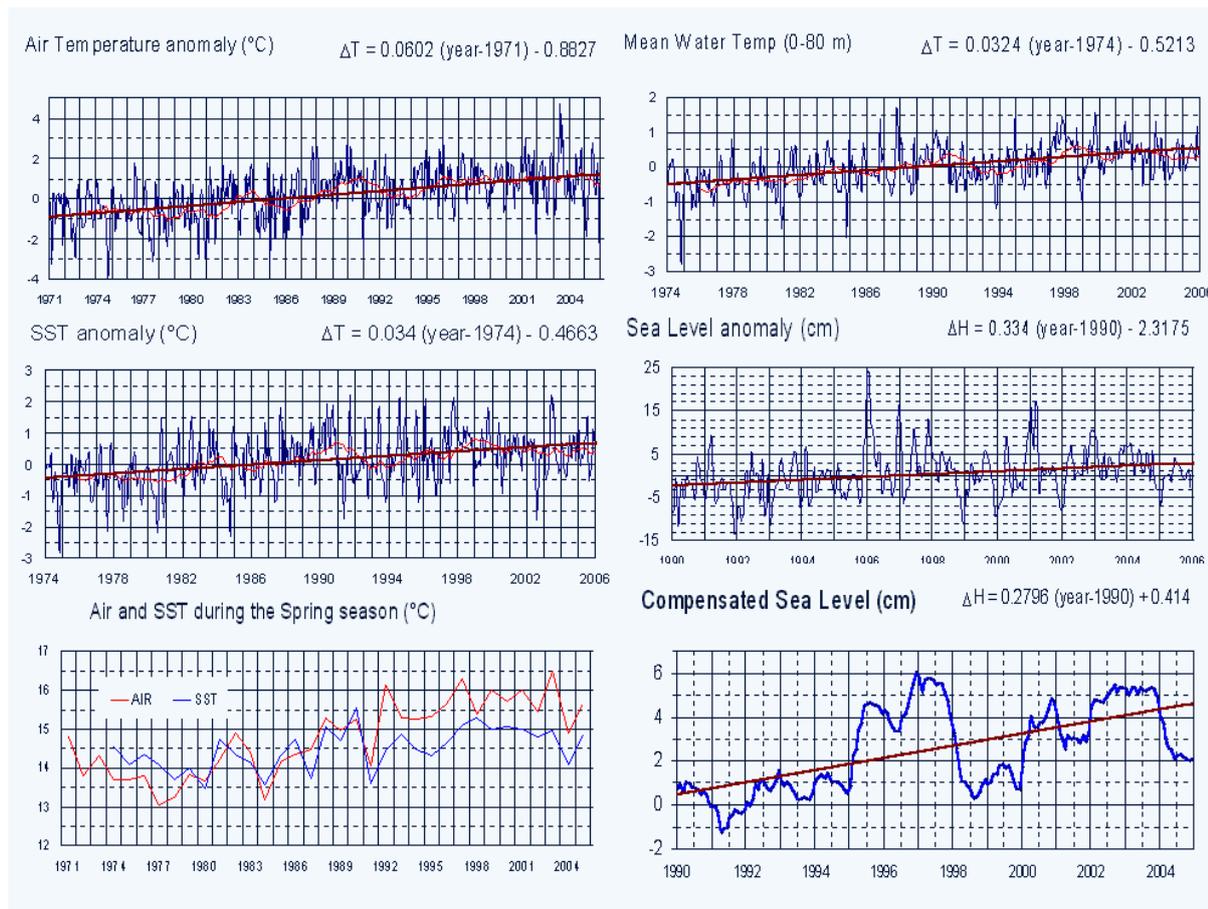


Figura 2: Augment de la temperatura de l'aire i dels mar en tots els nivells (de 0 a 80 m a L'Estartit). Màxima tendència d'augment de la temperatura durant els mesos de la primavera. Pujada neta del nivell del mar per l'efecte estèric (J. Salat, 2007).

3. Paper dels ecosistemes marins

L'impacte de la turbulència i de la producció biològica en les propietats òptiques dels oceans és un aspecte que s'ha de tenir en compte a l'hora de realitzar simulacions numèriques del clima. Per exemple, simulacions amb models acoblats oceà-atmosfera han mostrat la sensibilitat de la variabilitat

dels fenòmens d'El Niño quan s'introdueix el cicle anual de la clorofil·la en la parametrització de la difusivitat de la radiació solar a l'oceà Pacífic. La Figura 3 mostra els canvis en la modulació de la component zonal del vent en superfície segons es canvia la modulació de la clorofil·la, cosa que demostra que canvis en la clorofil·la en una regió poden ser comunicats a altres regions gràcies a l'acció dels vents.

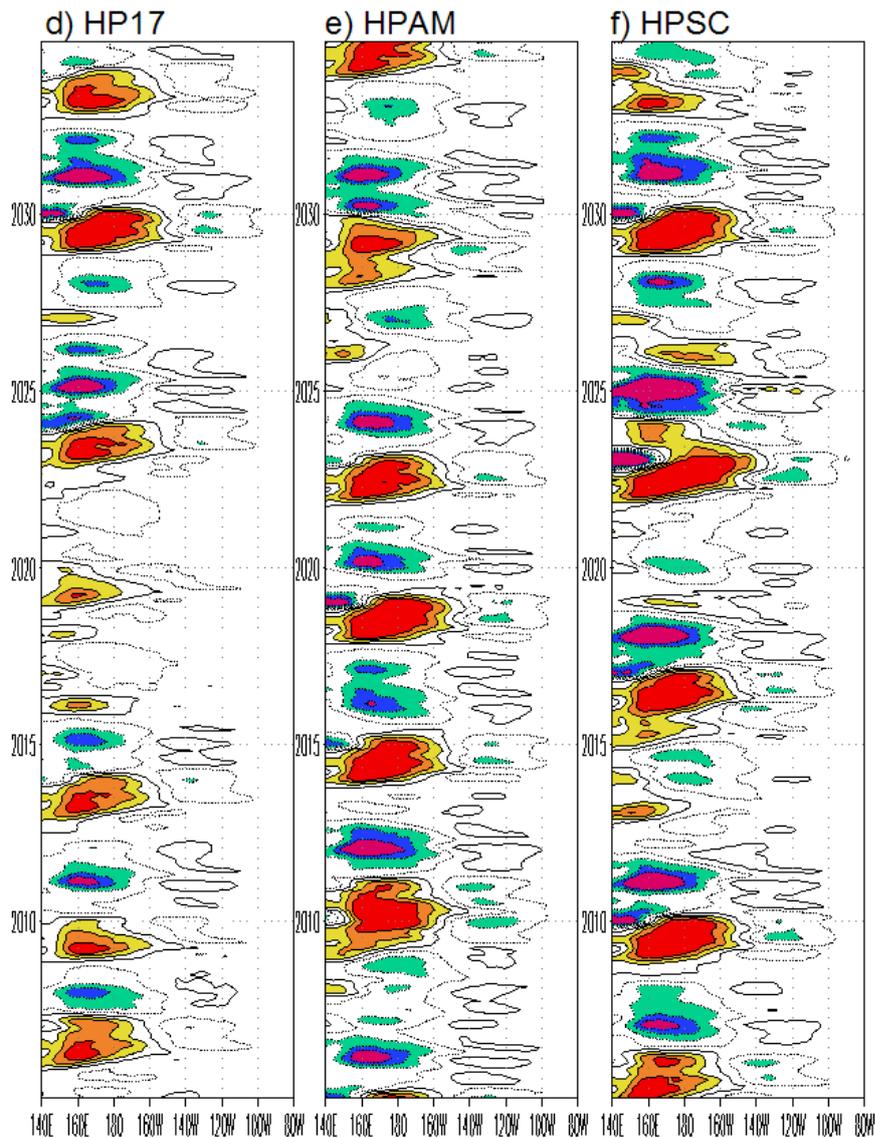


Figura 3: Evolució temporal de les anomalies de la tensió de vent en superfície a la zona ecuatorial de l'oceà Pacífic obtingudes amb un model acoblat oceà-atmòsfera en funció de tres definicions de la profunditat d'atenuació de la llum. L'experiment HP17 utilitza un valor constant de 17 m. L'experiment HPAM utilitza una profunditat d'atenuació constant que depen del promig anual de la clorofila (SeaWiFS). L'experiment HPSC utilitza el cicle anual de la clorofila per a calcular una profunditat d'atenuació que canvia amb les estacions (Ballabrera-Poy et al., 2007).

4. Desenvolupaments metodològics d'aplicació a la recerca en canvi climàtic

Els investigadors del CMIMA-CSIC han desenvolupat i continuen desenvolupant tècniques d'anàlisi numèrica originals amb l'objectiu d'identificar estructures espacials coherents i/o la seva evolució temporal. Per exemple, el mètode de l'anàlisi multifractal que relaciona la cascada d'energia amb propietats geomètriques permet l'obtenció de camps de corrents en superfície a partir d'imatges de temperatura marina obtingudes des de satèl·lits (Figura 4).

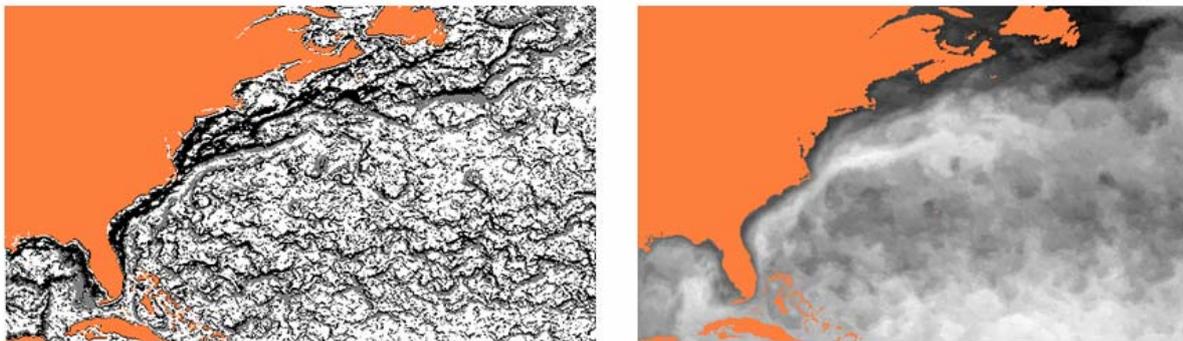


Figura 4: A l'esquerra es mostren els 33% punts més singulars obtinguts a partir de l'anàlisi de singularitat d'una imatge de SST (31 de Desembre del 2003). A la dreta, la funció de corrent derivada a partir dels punts més singulars. La obtenció de la funció de corrent equivalent a partir d'un model numèric requereix un cost de càlcul diversos ordres de magnitud més gran degut a la necessitat d'utilitzar simulacions d'alta resolució per aconseguir representar els gradients de temperatura amb la mateixa resolució que a la imatge (Turiel et al., 2005).

Projectes relacionats amb desenvolupaments operacionals d'aplicació a la recerca sobre el canvi climàtic

- **GYROSCOPE: Development of a real time in situ observing system in the North Atlantic Ocean, by an array of Lagrangian profiling floats** (EVK2-CT-2000-00087)
Finançament: 5^è Programa Marc de la Unió Europea
Investigador Principal: Y. Desaubies
Responsable d'Equip ICM: J. Font
Durada: 2001-2004
- **MAMA: Mediterranean network to Assess and upgrade Monitoring and forecasting Activity in the region** (EVR1-CT-2001-20010)
Finançament: 5^è Programa Marc de la Unió Europea, Red Temàtica (
Investigador Principal: S.Vallerga
Responsable d'Equip ICM: J. Font
Durada: 2002-2005

- **MFSTEP: Mediterranean ocean Forecasting System: Toward Environmental Predictions** (EUK3-2001-00174, REN2002-12249-E / MAR)
Finançament: 5^è Programa Marc de la Unió Europea
Investigador Principal: N. Pinardi
Responsable d'Equip ICM: J. Font
Durada: 2003-2006
- **ESEOO: Establecimiento de un Sistema Español de Oceanografía Operacional** (VEM2003-20577-C14)
Finançament: Acción Estratégica sobre actuaciones de I+D contra Vertidos Marinos Accidentales
Investigador Principal: E. Alvarez
Responsable d'Equip CSIC: E. García Ladona
Durada: 2003-2006
- **MERSEA: Marine Environment and Security for the European Area** (SIP3-CT-2003-502885)
Finançament: 6^è Programa Marc de la Unió Europea
Investigador Principal: Y. Desaubies
Responsable d'Equip CSIC: J. Font
Durada: 2004-2008

5. Desenvolupaments tecnològics d'aplicació a la recerca en canvi climàtic

La capacitat dels satèl·lits de proporcionar un flux d'informació global sobre l'estat de la Terra els fa un dels elements clau per a l'estudi de la variabilitat climàtica i dels efectes potencials d'un canvi climàtic. Conjuntament amb l'immens inventari d'observacions recollides durant campanyes oceanogràfiques, o amb ancoratges i flotadors, la informació proporcionada pels satèl·lits permet identificar tendències significatives sobre patrons del clima terrestre. Tanmateix, de totes les variables claus que assenyalen la variabilitat del clima terrestre, n'hi ha algunes que encara no es mesuren sistemàticament des de satèl·lits. El CMIMA-CSIC colidra el desenvolupament de la missió SMOS de l'Agència Europea de l'Espai (ESA) que es proposa mesurar la humitat del sòl i la salinitat dels oceans des de l'espai.

Projectes tecnològics per a aplicacions de tipus climàtic

- **SMOS: Soil Moisture and Ocean Salinity** (ESP2001-4523-PE, ESP2002-11604-E, ESP2004-00671, ESP2005-06823-C05-1, 14188/00/NL/DC, 14273/00/NL/DC, 15950/02/NL/SF, 16027/02/NL/GS, 18176/04/NL/CB, 18933/05/NL/FF)
Finançament: ESA, P.N. Espai
Coordinador: J. Font
Durada: 2000-
- **GRAC. Desarrollo de un sistema para medidas geocéntricas del nivel del mar basado en boyas GPS. Aplicación a la determinación de corrientes marinas en el Mediterráneo**

Noroccidental (2FD97-0588)

Finançament.: P. N. I+D (50%), Fondos FEDER (50%)

Investigador Principal: J. Font

Durada: 1999-2001

- **GRAC-II. Radar Altimeter-2 calibration with light GPS buoys** (15349/01/NL/SF)

Finançament: Agència Espacial Europea

Investigador Principal: A. Rius

Responsable d'Equipo J. Font

Durada: 2001-2005

- **Argo drifters in the Canary Basin**

Finançament: Groupe Mission Mercator Coriolis, France

Durada: 2006-2007.

6. Influència dels factors ambientals sobre organismes i comunitats

Els ecosistemes marins són vulnerables a les fluctuacions ambientals. La variabilitat climàtica té efectes importants en les fluctuacions d'abundància i dinàmica de les poblacions d'organismes marins (Figura 5) així com en l'evolució de les interaccions multispecífiques i les relacions tròfiques. Des del CMIMA s'estudien els factors ambientals que determinen la supervivència de les primeres fases de desenvolupament dels individus i que intervenen de forma significativa en els processos de reclutament. Una línia de recerca associada és l'estudi de la interacció genotip-ambient i les respostes adaptatives dels organismes i s'investiga l'efecte dels canvis temperatura, llum, concentració de nutrients i l'hidrodinamisme sobre la dinàmica i activitat dels organismes marins, tant en zones costaneres com a mar obert. A més, també es tenen en compte les alteracions en els patrons meteorològics, i s'estudia específicament com repercuteixen els canvis en la freqüència i la intensitat d'episodis extrems (p. ex., tempestes, llevantades, etc..) en l'estructura i producció marina.

Projectes sobre la influència de factors ambientals

- **MAS: Análisis de la estructura espacial de los primeros estadios de desarrollo de la merluza, anchoa y sardina en el Mediterráneo noroccidental. Interacción con la hidrografía y la disponibilidad trófica** (CTM2004-03510-C02-01/MAR)

Investigadora Principal: M. P. Olivar.

Durada: 2004-2007.

- **EnviEFH: Environmental approach to essential fish habitat designation.** (FP6-SSP8-022466)

Coordinador: Vasilis Valavanis

Responsable ICM: P. Martín.

Durada: 2005-2007

- **ANREC: Association of physical and biological processes acting on recruitment and post-**

recruitment of anchovy. (Q5RS-CT-2002-01216).

Coordinador: A. Kallianotis

Investigadora Principal ICM: I. Palomera.

Durada: 2002-2005

- **CACO: Estudio del efecto del cambio global en comunidades marinas del Mediterráneo nor-occidental** (REN2002-01339/MAR)
Investigadora Principal ICM: A. Sabatés
Durada: 2002-2005.
- **IDEA: Influencia de la estructura y dinámica oceanográfica sobre poblaciones demersales en aguas de las Islas Baleares.**
Finançament: CICIT
Investigador Principal: E. Massutí
Investigador Principal ICM: J. Cartes.
Durada: 2002-2006.
- **ARO: Estudio de la advección de aguas del Ródano hacia la costa Catalana a finales de primavera y sus implicaciones en el transporte de larvas de anchoa y comunidades planctónicas asociadas.**
Investigadora Principal ICM: A. Sabatés.
Durada: 2000-2001.
- **VARITEC. Aproximación multiescala a la variabilidad de la turbulencia y su efecto sobre la estructura y la dinámica del ecosistema costero en el Mediterráneo noroccidental.**
Finançament: Ministerio de Educación y Ciencia.
Investigador Principal: F. Peters
Durada: 2004-2007.
- **SPICOSA. Science and Policy Integration for Coastal Systems Assessment.**
Finançament: Unió Europea.
Investigadora Principal: D. Blasco
Durada: 2007-2010
- **Dinámica poblacional de especies longevas de invertebrados marinos Mediterráneos: efectos del cambio global y aspectos aplicados a su conservación.**
Finançament: Ministerio de Educación y Ciencia
Investigador Principal: Rafel Coma
Col·laboradora del CMIMA: M. Ribes
Durada:
- **NUTRIBEN. Papel del bentos en los ciclos biogeoquímicos costeros: remineralización vs retención de nutrientes por parte de comunidades bentónicas dominadas por esponjas.**
Finançament: Ministerio de Educación y Ciencia.
Investigadora Principal: M. Ribes
Durada: 2007-2009
- **Evolution et Conservation de la biodiversité marine face au changement global : le cas des**

communautés à dominance d'espèces longévives de Méditerranée.

Finançament: Agence Nationale de la Recherche.

Investigador Principal: Joaquim Garrabou.

Col·laboradora del CMIMA: M. Ribes

Durada: 2005-2008

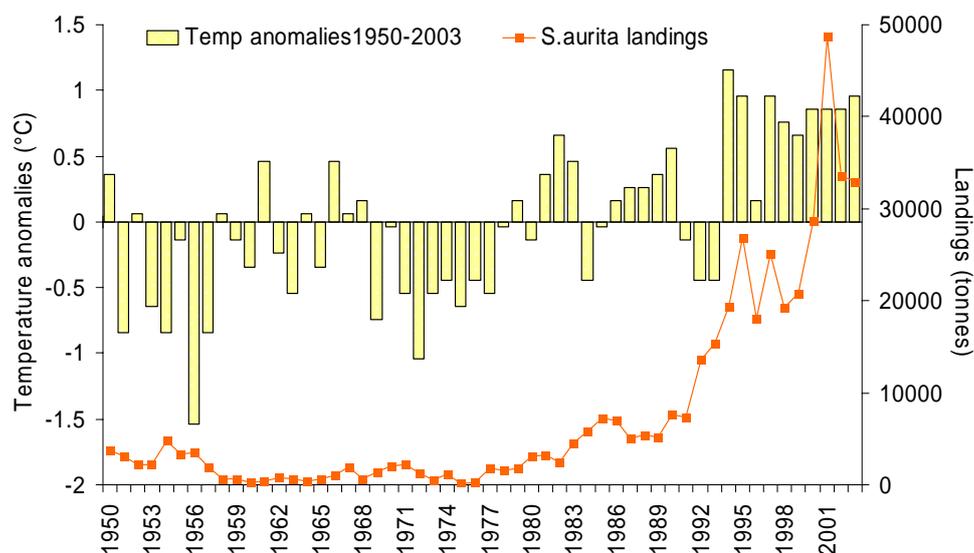


Figura 5: Captura anual de alatxa (*Sardinella aurita*) desembarcada a la Mediterrània occidental vs anomalies anuals de temperatura 1950-2003 ($r=0.62$; $P<0.01$) (Sabatés et al. 2006).

7. Biogeoquímica del clima

Juntament amb els fluxos de calor i de moment, un dels motors del clima tant a llarg com a curt termini són els fluxos de matèria entre compartiments ambientals i, molt especialment, a través de l'atmosfera. A ningú no s'escapa que la composició de l'atmosfera en determina les propietats radiatives i, de retruc, determina en bona mesura el balanç d'energia del planeta. Els fluxos de substàncies d'interès climàtic entre l'oceà i l'atmosfera estan controlats per processos abiòtics (dissolució i ventilació, fotoquímica) i processos i estructures biològiques (relacions tròfiques, produccions, fotobiologia, diversitat). De fet, la relació entre la biogeoquímica oceànica i el clima és bidireccional, i s'organitza en retroaccions positives i negatives. Al CMIMA-CSIC es du a terme recerca en l'intercanvi de sofre volàtil i aerosols entre l'oceà i l'atmosfera, els controls biològics d'aquest intercanvi i el seu impacte en la formació de núvols (Figura 6). També s'estudia l'efecte de l'escalfament (Figura 7), el desglaç i l'augment de la radiació UV sobre els processos metabòlics i la diversitat en les xarxes tròfiques planctòniques (des de virus a protistes), que determinen l'intercanvi biològic de CO₂ amb l'atmosfera. Finalment, s'investiguen els efectes de la progressiva acidificació dels oceans (que es deriva de l'absorció de bona part de l'excés de CO₂ antropogènic a l'atmosfera) sobre els organismes marins.

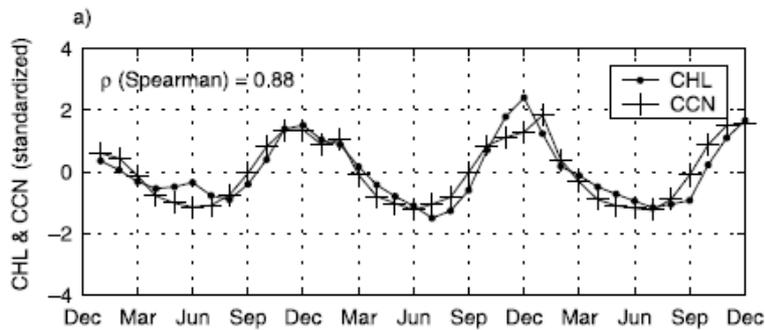


Figura 6: Variació de la concentració de chlorofil·la (CHL) a la superfície del mar i l'abundància de nuclis de condensació de núvols (CCN) a l'atmosfera entre 2002 i 2004. Ambdues variables obtingudes des de satèl·lits orbitals (Vallina et al. 2006).

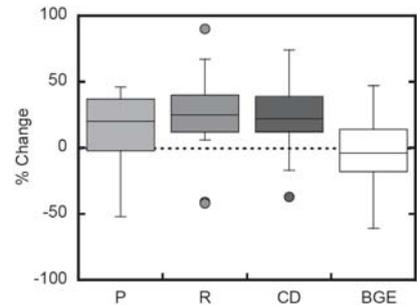


Figura 7: Canvis en la producció (P), respiració (R), demanda de carboni (CD) i eficiència de transferència de carboni (BGE) de microorganismes planctònics sotmesos a un escalfament de 2.5 graus respecte a la temperatura in situ. Mostres preses a l'Obs. Microbià de la Badia de Blanes durant els anys 2003-2004. (Vázquez-Domínguez. et al. 2007).

Projectes en temes de Biogeoquímica del clima

- **ATOS: Atmospheric inputs and organic carbon and pollutants to the Polar Ocean: rates significance and outlook. A Spanish component of the OASIS program. (EOL 147)**
 Finançament: MEC.
 Investigador Principal: Carlos Duarte
 Investigador Principal I'ICM: M. Alcaraz, A. Calbet, E. Saiz, R. Simó, D. Vaqué.
 Durada: 2006-2009
- **TEMPANO. Efecto de la temperatura sobre la estructura y metabolismo de las comunidades planctónicas Antárticas. (REN2001-0588).**
 Finançament: MEC
 Investigador Principal: D. Vaqué
 Durada: 20023-2003
- **AMIGOS. Algoritmos, Modelos e Integraciones Globales para el estudio del Océano Superficial y su papel ante el Cambio Global. (REN2001-3462/CLI)**
 Finançament: MEC
 Investigador Principal: R. Simó
 Durada: 2002-2004.
- **BIOCOMPLEXITY— Complex molecular to global interactions and feedbacks in the marine DMS cycle.**

Finançament: NSF (USA).
Coordinadora: Dra. Patricia Matrai (USA)
Investigador Principal a l'ICM: R. Simó
Durada: 2003-2006.

- **CAOS. Ciclo del Azufre en el Océano Superficial.** (CTM2004-20022-E)
Finançament: MEC.
Investigador Principal: R. Simó
Durada: 2005-2006.
- **EUR-OCEANS.**
Finançament: Xarxa d'Excel·lència del VI Programa Marc de la UE.
Investigador Principal a l'ICM: R. Simó, M. Alcaraz, D. Vaqué, J.M. Gasol
Durada: 2005-2008.
- **MIMOSA. Modelización de los Intercambios de Materia entre el Océano Superficial y la Atmósfera** (CTM2005-06513/MAR)
Finançament: MEC
Investigador Principal: R. Simó
Durada: 2006-2008
- **Grup de Recerca en Biogeoquímica Marina i Canvi Global.**
Finançament: Grup Emergent de Qualitat de la Generalitat de Catalunya.
Investigador Principal: R. Simó
Durada: 2006-2009
- **OCEANTARTIC. Origen, ciclo y emisión de azufre volátil en aguas antárticas.**
Finançament: MEC.
Investigador Principal: R. Simó
Durada: 2006-2007.

8. Paleoceanografia i Paleoclimatologia

Per poder diferenciar i entendre el paper de l'home en l'actual canvi climàtic, és essencial establir la variabilitat natural dels processos i paràmetres relacionats amb el clima. Avui en dia disposem d'un ventall considerable d'indicadors indirectes, mesurats en determinats materials o arxius climàtics, que ens proporcionen informació quantitativa sobre paràmetres claus com, per exemple, la temperatura, la salinitat i el pH de l'aigua del mar. El CMIMA compta amb investigadors amb experiència en el camp de les reconstruccions climàtiques i oceanogràfiques pretèrites que, per una banda, desenvolupen i apliquen nous arxius climàtics i indicadors de la química oceànica i, per altra banda, reconstrueixen la composició i les característiques fisicoquímiques de les aigües marines en el passat (p. ex., nutrients, temperatura, pH) mitjançant anàlisis geoquímiques de sediments marins i coralls. Exemple d'una nova línia de recerca en aquest terreny és la primera reconstrucció del pH de l'aigua del mar pels darrers 300 anys mitjançant anàlisis d'isòtops de bor en un corall del nord-est d'Austràlia (Figura 8).

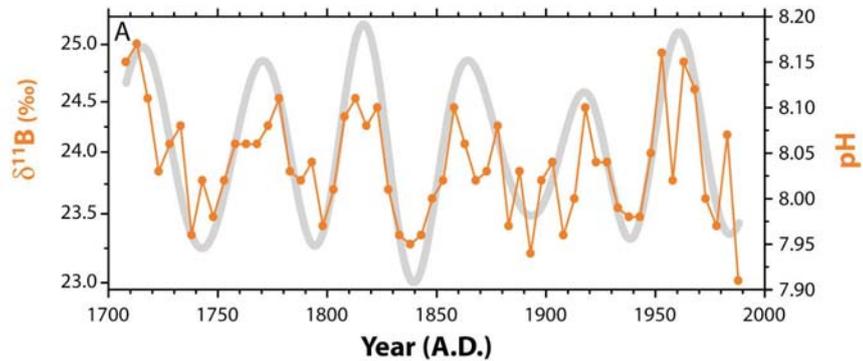


Figura 8: Esquerra: Tot mostrejant un corall *Porites*. Dreta: Registre de pH marí pels darrers 300 anys reconstruït mitjançant la composició isotòpica de bor ($\delta^{11}\text{B}$) d'un corall de l'Escull de Flinders (Mar del Corall). S'observa una ciclicitat característica amb periodicitat aproximada de 50 anys (adaptat de Pelejero, Calvo et al., *Science*, 2005).

Projectes en temes de paleoceanografia o paleoclimatologia

- **ROMIAT: Efectos y respuesta de los organismos marinos ante la inminente acidificación d'elos océanos: Un estudio multi-temporal.**
 Finançament: Ministerio de Educación y Ciencia.
 Investigador Principal: C. Pelejero
 Durada: 2007-2009
- **The key role of the Southern Ocean in atmospheric CO₂ sequestration.**
 Finançament: Australian Research Council.
 Investigador Principal: E. Calvo
 Durada: 2004-2005
- **Uptake of atmospheric CO₂ in the oceans and implications for global change: New proxy developments.**
 Finançament: Australian Research Council.
 Investigador Principal: C. Pelejero
 Durada: 2003-2005

Annexes: Llistat de publicacions d'investigadors de l'ICM rellevants al clima

A-1. Recerca per a la caracterització de la variabilitat anual e interanual

[Astraldi, M., S. Balopoulos, J. Candela, J. Font, M. Gacic, G. P. Gasparini, B. Manca, A. Theocharis, and J. Tintoré, The role of straits and channels in the understanding the characteristics of Mediterranean circulation, Prog. Oceanogr., 44\(1-3\): 65-108 \(1999\).](#)

Straits in the Mediterranean Sea form an important network from which one can determine the characteristics of the water exchange between all the constituent sub-basins. This includes the definition of water masses and their time variability. From 1994, all the major straits in the Mediterranean Sea (Gibraltar, Sicily, Otranto, Balearic Sea Straits, Cretan Are Straits and Corsica) were subject to long term observations as part of various research projects. Besides adding new elements to the knowledge of internal strait conditions, the data sets collected allow us to propose a fairly consistent representation of the Mediterranean circulation and budgets in key points within the basin. The amplitude of the annual water transport measured at these straits was about 1 Sv and it appears to be modulated by a significant low-frequency and seasonal variability. For the first time, a seasonal component was identified at Gibraltar, thus raising new questions on the actual state of the Mediterranean. Also, the very likely existence of a significant interannual component was documented, in the Corsica Channel, this component was found to be related to the interannual variability of the North Atlantic Oscillation. The observations in the Cretan Are Straits have provided a more comprehensive representation of the recent changes in the Eastern Mediterranean thermohaline cell. It is noteworthy that the effects of these changes have been observed both in the Otranto and Sicily Straits, and are now affecting the adjacent sea regions. The presence of a stream of Modified Atlantic Water in the Balearic Sea Channels indicates that part of the Atlantic inflow may be diverted directly into the northern region of the Western Mediterranean. Finally, data gathered in the Sardinia Channel indicate that the central Mediterranean region plays a critical role in controlling exchanges between the Eastern and the Western Mediterranean, while it is emphasized that the Tyrrhenian Sea area plays a role in strongly modifying some of the water masses that contribute to the large scale basin circulation. Their mixing creates new water types which modify the currently known pattern and composition of the Mediterranean circulation.

[Ratsimandresy, A. W., J. L. Pelegrí, A. Marrero-Díaz, A. Hernández-Guerra, A. Antoranz, and A. Martínez, Seasonal variability of the upper warmwatersphere in the Canary Basin, Scientia Marina, 65\(S1\), 251-258. \(2001\)](#)

Two years of periodic XBT data, along seven transects covering the Canary Basin, were examined to analyse the seasonal cycle of the upper layers of the warmwatersphere. This is characterised by seasonal storage/release of heat in the surface mixed layer and by the winter formation of a subsurface positive temperature anomaly. Its maximum value takes place in early winter and deepens to about 150 m in late spring, disappearing afterwards. We present a very simple argument, which illustrates how the evolution of the temperature anomaly is controlled both by the ocean-atmosphere heat exchange and by the shape of the North-Atlantic Central Water T-S relationship.

[Hernández-Guerra, A., F. López-Laatzén, F. Machín, D. de Armas, and J. L. Pelegrí, Water masses, circulation and transport in the eastern boundary current of the North Atlantic subtropical gyre, Scientia Marina, 65\(S1\), 177-186. \(2001\)](#)

CTD sections carried out in September 1998 are used to describe the water masses, geostrophic circulation and mass transport in the easternmost branch of the Canary Current. The surface water mass (< 600 m) consists of North Atlantic Central Water (NACW) flowing south with a net mass transport of 2.3×10^9 kg s⁻¹. A tongue of relatively fresh water, consisting of Antarctic Intermediate Water (AAIW), was found approximately in the 600-1100 m depth layer. This tongue was 200 km wide, stretching from the African coast almost to Gran Canaria Island, and transported a net mass of 1.1×10^9 kg s⁻¹ northward. This system of currents is what constitutes the real eastern boundary current of the North Atlantic Subtropical Gyre.

[Bouzinac, C., J. Font, and J. Johannessen, The annual cycles of sea level and sea surface temperature in](#)

[the western Mediterranean Sea, J. Geophys. Res., 108\(C3\): 3059, doi:10.1029/2002JC001365 \(2003\)](#)

In the western Mediterranean Sea, sea level variations are the result of seasonal steric effect, atmospheric forcing and mesoscale circulation activity, particularly in the Alboran and Algerian basins, as well as water mass budget variations including flux variations through the Straits of Gibraltar and Sicily. However, the partition of the magnitude of the sea level variations associated with these different components remains a challenging problem. A better determination of the steric effect component will allow a better knowledge of the other annual components. The aim of this study is to improve the estimation and understanding of the annual sea level variations in the different basins of the western Mediterranean Sea, using sea level anomalies (SLA) derived from TOPEX/POSEIDON and ERS-1/2 altimeters and sea surface temperatures (SST) derived from NOAA/AVHRR infrared imagery, obtained between 1992 and 1998. The first mode of empirical orthogonal function (EOF) analysis on SLA is annual and represents 63% of the total variance. The first mode of EOF analysis on SST anomalies is also annual and represents 98% of the total variance. The lag between the annual variations of SLA and SST is about 40 days. From these EOF results and a parameterisation of the mixed layer, the seasonal dynamic height and the steric effect are estimated and removed from the SLA. The remaining signal is used to examine the annual cycles of the sea level due to water mass budget variations, mesoscale oceanic variability and atmospheric forcing.

[Ostrovskii, A., and J. Font, Advection and dissipation rates in the upper ocean mixed layer heat anomaly budget over the North Atlantic in summer, J. Geophys. Res., 108 \(C12\): 3376, doi:10.1029/2003JC001967 \(2003\)](#)

Processes contributing to the heat anomaly budget of the upper ocean mixed layer are examined over the North Atlantic in summer season on the basis of the inversion of the sea temperature profiles. The net advection velocity, the subgrid heat diffusivity, and the surface heat flux feedback are estimated. Two inversion strategies are pursued, with and without the explicit parameterization of the entrainment heat flux into the upper mixed layer. The regression estimator is employed for the inversion. The data involved are the compilation of the Comprehensive Ocean-Atmosphere Data Set sea surface temperature (SST) and World Ocean Database 2001 temperature profiles over a 2° latitude x 3° longitude grid for sequential 10-day intervals in June-September during 1965-2000. The inversion is constrained by the autocorrelation of the National Centers for Environmental Prediction net air-sea heat flux. The regression estimator allows for prediction of up to 60-70% of the SST anomaly value 10 days in advance by using the regressions on the SST anomalies lagged by two time steps. The SST anomaly transport over the North Atlantic agrees broadly with the known features of the surface circulation, although the quantitative details of the SST anomaly propagation obtained in this inversion have not previously been available. The heat anomaly that originates in the Gulf Stream region near the western boundary either moves northeastward with speed of up to 0.12 m s⁻¹ downstream of the North Atlantic Current and the North Atlantic Drift Current or it turns southeastward and then propagates southwestward along the broad subtropical recirculation; in the subtropics the westward propagation is seemingly reinforced by the effects of the planetary waves. The air-sea feedback is negative with the feedback factor having the average value of 39 W m⁻² K⁻¹ with substantial variations throughout the North Atlantic. The entrainment rate is generally about 0.15 m d⁻¹; relatively rapid deepening of the mixed layer by more than 2 x 10⁻⁶ m s⁻¹ occurs near the Gulf Stream.

[Pelegrí, J. L., J. Arístegui, L. Cana, M. González, A. Hernández-Guerra, S. Hernández-León, A. Marrero-Díaz, M. F. Montero, P. Sangrá, and M. Santana-Casiano, Coupling between the open ocean and the coastal upwelling region off Northwest Africa: Water recirculation and offshore pumping of organic matter, J. Mar. Sys., 54, 3-37 \(2005\)](#)

The surface and upper-thermocline waters of the Canary Basin are characterised by very strong coupling between the open ocean and the coastal upwelling region. Such coupling has its origin in water inflow into the upwelling region north of the Canary Islands and its recirculation south along the continental slope, which is the true Canary Current. A portion of this recirculating water is intermittently exported offshore through surface filaments. During late fall, a major diversion takes place at Cape Ghir, allowing the presence of northward flow from Cape Blanc till Cape Yubi. The fraction of water that flows through the Canary Archipelago is the origin of intense mesoscale variability south of the Canary Archipelago, which interacts strongly with the coastal region. These physical characteristics are responsible of intense alongshore and vertical fluxes of nutrients and dissolved inorganic carbon within the upwelling region. Coastal filaments and cyclonic eddies cause localised offshore export of nutrients and organic matter, making possible that respiration be several times larger than production in the open ocean. A major characteristic of the ecosystem comes from the seasonal variation in the current pattern, allowing coastal convergence and intense transfer of coastal properties to the open ocean during late fall.

[Emelianov, M., J. Font, A. Turiel, C. Millot, J. Solé, P. Poulain, A. Julià, and M. R. Vitrià, Transformation of Levantine Intermediate Water tracked by MedArgo floats in Western Mediterranean Ocean Sci., 2: 281-290, www.ocean-sci.net/2/281/2006/ \(2006\)](#)

A clustering methodology is applied to investigate the thermohaline structure of Levantine Intermediate Water (LIW) in the western Mediterranean basin. Sixteen freedrifting hydrographic profilers were deployed in the framework of the MFSTEP project (MEDARGO component) from September 2003. A total of 925 CTD profiles collected up to the beginning of February 2006 have been used in the analysis. The results are in good agreement with the general circulation scheme for intermediate waters in the basin and confirm the hypothesis about a “discrete-continuous” thermohaline structure of LIW.

A-2. Recerca en variabilitat climàtica

[Murtugudde, R., J. Ballabrera-Poy, J. Beauchamp, and A. J. Busalacchi, Relationship between zonal and meridional modes in the tropical Atlantic, *Geophys. Res. Lett.*, 28, 4463-4466 \(2001\)](#)

The tropical Atlantic displays two main modes of variability; the meridional or dipole mode and the equatorial zonal mode. It was proposed recently, that these two modes are correlated and are both forced within the tropics by latitudinal displacements of the ITCZ. This modeling study shows that while the two modes are correlated for limited record lengths prior to and after 1976, the correlation falls apart when longer time-series from 1949 to 2000 are considered. The 1976 'climate shift' also occurred in the tropical Atlantic seen as a thermocline shift similar to the Pacific, forced dynamically within the tropics. The first EOF of the simulated thermocline depth captures the interdecadal mode with the 1976 shift. The first EOF of SST anomalies prior to (after) 1976 represents the meridional (zonal) mode, consistent with the previous finding that the relation between the eastern Pacific and Atlantic ITCZ is stronger in the 1980-90's.

[Vargas-Yáñez, M., J. Salat, M.L. Fernández de Puelles, J.L. López-Jurado, J. Pascual, T. Ramírez, D. Cortés, and I. Franco, Trends and time variability in the northern continental shelf of the western Mediterranean. *J. Geophys. Res.*, 110: C10019 \(2005\)](#)

Different works appearing during the last decade show that the western Mediterranean has suffered a temperature and salinity increase during the 20th century. Most of these works analyze long-term trends in Levantine Intermediate Water (LIW) and Western Mediterranean Deep Water (WMDW); those dealing with changes in shallow and coastal waters are very scarce. It is still an open question whether these changes are due to meteorological factors occurring in the western Mediterranean or if they are caused by the salinity increase of the water masses contributing to deep water formation. In this work we analyze the data obtained in the last decade of the 20th century (and longer time series in some cases) within the frame of six projects aimed at the systematic collection of hydrographic data at fixed stations in the northern sector of the western Mediterranean (mainly in coastal areas). We detect strong warming trends in those stations located in the continental shelf (and probably with no influence of the LIW). This result could indicate that changes observed in the WMDW cannot be explained only on the basis of changes imported from the eastern basin. Another striking result is that these trends are an order of magnitude higher than those reported for the rest of the century, indicating that the 1990s have been an exceptionally warm decade. On the other hand, time series affected by the LIW show a salinity increase, and in some cases this is not accompanied by the corresponding temperature increment, indicating that the LIW salinity increase could also be a factor to be taken into account.

[Font, J., P. Puig, J. Salat, A. Palanques, and M. Emelianov, Sequence of hydrographic changes in the NW Mediterranean deep water due to the exceptional winter 2005, *Sci. Mar.*, 71\(2\): 339-346 \(2007\)](#)

Time series measurements at a mooring site on the deep slope of the NW Mediterranean from October 2003 to July 2005 revealed the sequence of effects of the anomalously dry, markedly cold, and very windy winter of 2005 in deep water thermohaline properties. At the end of January, a dense water mass that was warmer and saltier than usual reached the deep slope mooring site. Almost simultaneously, the start of deep dense shelf water cascading episodes was observed in the Gulf of Lions' submarine canyons. 30 days later, colder, fresher and even denser waters reached the mooring, with a 5-day delay from an intensification of the Gulf of Lions' cascading. The signature of these waters was detected for 35 days, and by late spring 2005 a new stable water mass situation was reached, with higher thermohaline values than those that characterised the deep layer from October 2003 to January 2005.

[Solé, J., A. Turiel, and J. E. Llebot, Using Empirical Mode Decomposition to correlate paleoclimatic time-series, *Natural Hazards and Earth System Sciences* 7, 299-307 \(2007\)](#)

Determination of the timing and duration of paleoclimatic events is a challenging task. Classical techniques for time-series analysis rely too strongly on having a constant sampling rate, which poorly adapts to the uneven time recording of paleoclimatic variables; new, more flexible methods issued from Non-Linear Physics are hence required. In this paper, we

have used Huang's Empirical Mode Decomposition (EMD) for the analysis of paleoclimatic series. We have studied three different time series of temperature proxies, characterizing oscillation patterns by using EMD. To measure the degree of temporal correlation of two variables, we have developed a method that relates couples of modes from different series by calculating the instantaneous phase differences among the associated modes. We observed that when two modes exhibited a constant phase difference, their frequencies were nearly equal to that of Milankovich cycles. Our results show that EMD is a good methodology not only for synchronization of different records but also for determination of the different local frequencies in each time series. Some of the obtained modes may be interpreted as the result of global forcing mechanisms.

[Solé, J., A. Turiel, and J. E. Llebot, Classification of Dansgaard-Oeschger climatic cycles by the application of similitude signal processing, *Physics Letters A* 366, 184-189 \(2007\)](#)

In this work we have performed a detailed analysis, using signal processing tools, to study time series of data (temperature proxy) extracted from the GRIP ice-core records and we relate it with the evolution of atmospheric CO₂ within the last glacial period. Our method is based in considering the warm periods known as Dansgaard-Oeschger (D/O) events and posterior returns to the cold stage as a climatic cycle. After the warming phase, D/O events relax to the initial cold state in three different ways, what gives rise to three classes of cycles. Also, the Younger/Dryas-Bolling/Allerod (Y/D-B/A) cycle corresponds to one of the classes obtained. We have found that all cycles start with identical warming phases which seem completely unrelated to variations in CO₂ concentration. We discuss on the consequences for global climatology of such steady pattern of cycles.

A-3. Paper dels ecosistemes marins

[García-Muñoz, M., A. Antoranz, J. Arístegui, J. L. Pelegrí, and M. Torres, Exchange of carbon and nutrients off Cape Ghir \(NW Africa\), *J. Mar. Sys.*, 54, 83-95. \(2005\)](#)

We have studied the physicochemical and biological structure of a permanent filament off Cape Ghir (31 degrees N) and estimated the transport of organic matter associated with it. The seaward filament exported coastal upwelled water, with low temperature and salinity and high organic matter, to the open ocean even in the absence of upwelling-favorable conditions. The estimated flux of excess organic carbon (the nonrefractory pool) expressed in annual basis yielded a value of 3.1×10^9 kg C, from which similar to 90% was transported as dissolved organic carbon. This flux represents about 63% of the average annual primary production for the region of study. We conclude that the net-offshore transport may contribute to the enrichment of offshore oligotrophic waters throughout the year, partly explaining the metabolic imbalance found in open ocean waters of the subtropical Northeast Atlantic.

[Ballabrera-Poy, J., R. Murtugudde, R.-H. Zhang, and A. J. Busalacchi, Coupled ocean-atmosphere response to seasonal modulation of ocean color: Impact on interannual climate solutions in the tropical Pacific, *J. Climate*, 20, 353-374 \(2007\)](#)

The ability to use remotely sensed ocean color data to parameterize biogenic heating in a coupled ocean-atmosphere model is investigated. The model used is a hybrid coupled model recently developed at the Earth System Science Interdisciplinary Center (ESSIC) by coupling an ocean general circulation model with a statistical atmosphere model for wind stress anomalies. The impact of the seasonal cycle of water turbidity on the annual mean, seasonal cycle, and interannual variability of the coupled system is investigated using three simulations differing in the parameterization of the vertical attenuation of downwelling solar radiation: (i) a control simulation using a constant 17-m attenuation depth, (ii) a simulation with the spatially varying annual mean of the satellite-derived attenuation depth, and (iii) a simulation accounting for the seasonal cycle of the attenuation depth. The results indicate that a more realistic attenuation of solar radiation slightly reduces the cold bias of the model. While a realistic attenuation of solar radiation hardly affects the annual mean and the seasonal cycle due to anomaly coupling, it significantly affects the interannual variability, especially when the seasonal cycle of the attenuation depth is used. The seasonal cycle of the attenuation depth interacts with the low-frequency equatorial dynamics to enhance warm and cold anomalies, which are further amplified via positive air-sea feedbacks. These results also indicate that interannual variability of the attenuation depths is required to capture the asymmetric biological feedbacks during cold and warm ENSO events.

A-4. Desenvolupaments metodològics d'aplicació al canvi

climàtic

[Bouzinac, C., J. Vázquez, and J. Font, Complex Empirical Orthogonal Functions analysis of ERS-1 and Topex/Poseidon combined altimetric data in the region of the Algerian current, J. Geophys. Res., 103\(C4\): 8059-8071 \(1998\).](#)

Maps of sea level anomalies (SLA) relative to the 1993 annual mean sea level combine the data from the two altimetric missions, ERS-1 and TOPEX/POSEIDON, during the overlap period (October 1992 to December 1993). These regular maps in space and time of residual sea level every 10 days on a 0.2 degrees regular grid are used in the region of the Algerian current where the mesoscale eddies are of primary importance to the circulation of all the Mediterranean water masses. They are first compared with ERS-1 along-track scanning radiometer sea surface temperature images to get information on two anticyclonic eddies produced by instabilities of the Algerian current and visible in both infrared and altimetric data sets. Then, an analysis of complex empirical orthogonal functions (CEOFs) is performed on the SLA data set to see the correlation of the different dynamic features of the observed variability. The CEOF analysis is applied to the complex time series formed from the original SLA time series and their Hilbert transforms to separate the variability into spatially coherent modes. The spatially correlated signal in the study area (0-15 degrees E and 35 degrees-40 degrees N) was found to be dominated by the first two CEOFs. These first two modes explain nearly 85% of the variability, with 80% of the total variance for the first one and 5% of the total variance for the second one. The temporal phase of the first mode indicates that a constant frequency of one cycle per year is clearly dominant, corresponding to the seasonal signal. The strongest amplitude is obtained in the southern part of the channel of Sardinia and south of the Strait of Sicily. The temporal amplitude and the temporal phase of the second mode show a periodicity of about 6 months which appears to be associated with the variability of the Algerian current as the phase isolines are parallel to the mean current path along the Algerian coast. The strongest amplitude of the second mode is located near the African coast at similar to 4 degrees E and 8 degrees E. These two points of high variability could correspond to eddy detachments from the main current.

[Isern-Fontanet, J., E. García-Ladona, J. Font, Identification of marine eddies from altimetric maps, J. Atmos. Ocean. Technol., 20 \(5\): 772-778 \(2003\)](#)

A procedure is presented to detect eddy cores from sea level anomaly (SLA) maps obtained from altimetric measurements. The method is based on finding the sign of Q , which is an invariant of the velocity gradient tensor (delu). This parameter, commonly used in studies of two-dimensional turbulence, measures the relative contribution of deformation and vorticity. Vortex cores are associated with regions with large and positive values of Q . It is shown that this parameter is adequate to detect marine eddies in altimetric maps and, when the geometry of streamline contours in SLA maps is unclear, the $Q > 0$ criterion appears to work more consistently. The performance of the methodology is applied, as an example, to altimetric maps of the Algerian Basin in the Western Mediterranean Sea, where two long-lived eddies are tracked. The observed trajectories are in good agreement with Advanced Very High Resolution Radiometer (AVHRR) images.

[Turiel, A., J. Isern-Fontanet, E. García-Ladona, and J. Font, A multifractal method for the instantaneous evaluation of the stream function in geophysical flows, Phys. Rev. Lett., 95\(10\): Art. 104502 \(2005\)](#)

Multifractal or multiaffine analysis is a promising new branch of methods in nonlinear physics for the study of turbulent flows and turbulentlike systems. In this Letter we present a new method based on the multifractal singularity extraction technique, the maximum singular stream-function method (MSSM), which provides a first order approximation to the stream function from experimental data in 2D turbulent systems. The essence of MSSM relies in relating statistical properties associated with the energy cascade in flows with geometrical properties. MSSM is a valuable tool to process sparse collections of data and to obtain instant estimates of the velocity field. We show an application of MSSM to oceanography as a way to obtain the current field from sea surface temperature satellite images; we validate the result with independent dynamical information obtained from sea level measurements.

[Ruiz, S., D. Gomis, and J. Font, Recovery of North-East Atlantic temperature fields from profiling floats: determination of the optimal float number from sampling and instrumental error analysis, J. Marine Syst., 65: 212-223 \(2007\)](#)

Argo is an international project that is deploying an array of temperature and salinity profiling floats over the global ocean. Here we use the error formulation derived from Optimal Statistical Interpolation to estimate statistical errors associated with the recovery of the temperature field in the North-East Atlantic ocean. Results indicate that with the present distribution of floats (119 in the considered domain), scales of wavelength larger than 500 km can be recovered with a relative uncertainty (rms error relative to the standard deviation of the field) of about 7% at 50 m, 8% at 200 m and 10% at 1000 m. This

corresponds to mean absolute errors of 0.111 °C at 50 m, 0.104 °C at 200 m and 0.073 °C at 1000 m. The splitting of total errors into instrumental and sampling contributions reveals that, in the present scenario, errors are more due to the small number of floats than to instrumental errors, especially at upper levels. For scales larger than 500 km this will hold true until 200-250 floats are deployed (less than 200 for deep levels). In such a simulated scenario, the number of observations and the technology become approximately equally limiting factors for the accuracy of the temperature field mapping, with total relative errors of less than 2% at upper levels and about 3% at 1000 m.

A-5. Desenvolupaments tecnològics d'aplicació al canvi climàtic

Kerr, Y. H., P. Waldteufel, J. P. Wigneron, J. M. Martinuzzi, [J. Font](#), and M. Berger, Soil moisture retrieval from space: The Soil Moisture and Ocean Salinity (SMOS) mission, *IEEE T. Geosci. Remote*, 39 (8): 1729-1735 (2001)

Microwave radiometry at low frequencies (L-band: 1.4 GHz, 21 cm) is an established technique for estimating surface soil moisture and sea surface salinity with a suitable sensitivity. However, from space, large antennas (several meters) are required to achieve an adequate spatial resolution at L-band. So as to reduce the problem of putting into orbit a large filled antenna, the possibility of using antenna synthesis methods has been investigated. Such a system, relying on a deployable structure, has now proved to be feasible and has led to the Soil Moisture and Ocean Salinity (SMOS) mission, which is described in this paper. The main objective of the SMOS mission is to deliver key variables of the land surfaces (soil moisture fields), and of ocean surfaces (sea surface salinity fields). The SMOS mission is based on a dual polarized L-band radiometer using aperture synthesis (two-dimensional [2-D] interferometer) so as to achieve a ground resolution of 50 km at the swath edges coupled with multiangular acquisitions. The radiometer will enable frequent and global coverage of the globe and deliver surface soil moisture fields over land and sea surface salinity over the oceans. The SMOS mission was proposed to the European Space Agency (ESA) in the framework of the Earth Explorer Opportunity Missions. It was selected for a tentative launch in 2005. The goal of this paper is to present the main aspects of the baseline mission(1) and describe how soil moisture will be retrieved from SMOS data.

Camps, A., [J. Font](#), J. Etcheto, V. Caselles, A. Weill, I. Corbella, M. Vall-llossera, N. Duffo, F. Torres, R. Villarino, L. Enrique, [A. Julià](#), [C. Gabarró](#), J. Boutin, E. Rubio, S. C. Reising, P. Wursteisen, M. Berger, and M. Martín-Neira, Sea Surface Emissivity Observations at L-band: First Results of the Wind and Salinity Experiment WISE-2000, *IEEE T. Geosci. Remote.*, 40 (10): 2117-2130 (2002)

Sea surface salinity can be measured by passive microwave remote sensing at L-band. In May 1999, the European Space Agency (ESA) selected the Soil Moisture and Ocean Salinity (SMOS) Earth Explorer Opportunity Mission to provide global coverage of soil moisture and ocean salinity. To determine the effect of wind on the sea surface emissivity, ESA sponsored the Wind and Salinity Experiment (WISE 2000). This paper describes the field campaign, the measurements acquired with emphasis in the radiometric measurements at L-band, their comparison with numerical models, and the implications for the remote sensing of sea salinity.

Berger, M., A. Camps, [J. Font](#), Y. Kerr, J. L. Miller, J. Johannessen, J. Boutin, M. R. Drinkwater, N. Skou, N. Floury, M. Rast, H. Rebhan, and E. Attema, Measuring Ocean Salinity with ESA's SMOS Mission – Advancing the Science, *ESA Bull-Eur. Space*, 111: 113-121 (2002).

The Soil Moisture and Ocean Salinity (SMOS) mission is ESA's second Earth Explorer 'opportunity mission', scheduled for launch in early 2006. Selected for an extended feasibility (Phase-A) study in 1999, which was completed in December 2001, SMOS is currently in the design and development phase (Phase-B). SMOS will exploit an innovative instrument designed as a two-dimensional interferometer for acquiring brightness temperatures at L-band (1.4 GHz) to retrieve soil moisture and ocean salinity. Both are key variables used in weather, climate and extreme-event forecasting. As a secondary objective, data acquired by SMOS over ice/snow regions may be used to characterise the ice and snow layers and thus complement other satellite observations to advance the science of the cryosphere.

Camps, A., I. Corbella, M. Vall-llossera, N. Duffo, F. Torres, R. Villarino, L. Enrique, F. Julbe, [J. Font](#), [A. Julià](#), [C. Gabarró](#), J. Etcheto, J. Boutin, A. Weill, E. Rubio, V. Caselles, P. Wursteisen, and M. Martín-Neira, L-band sea surface emissivity: Preliminary results of the WISE-2000 campaign and its application to salinity retrieval in the SMOS mission, *Radio Sci.*, 38 (4): 8071,

[doi:10.1029/2002RS002629](https://doi.org/10.1029/2002RS002629) (2003)

Soil moisture and ocean salinity at surface level can be measured by passive microwave remote sensing at L-band. To provide global coverage data of soil moisture and ocean salinity with three-day revisit time, the Earth Explorer Opportunity Mission SMOS (Soil Moisture and Ocean Salinity) was selected by ESA (European Space Agency) in May 1999. SMOS' single payload is a Y-shaped 2-D aperture synthesis interferometric radiometer called MIRAS (Microwave Imaging Radiometer by Aperture Synthesis). SMOS presents some particular imaging peculiarities: variation of incidence and azimuth angles, different radiometric sensitivity and accuracy at each direction (pixels), and geometric polarization mixing. Therefore, the accuracy of the geophysical parameter retrieval depends on the knowledge of the angular dependence of the emissivity over a wide range of incidence and azimuth angles. The accuracy of the sea surface salinity retrievals depends on our capability to correct the wind-induced variation of the brightness temperatures. To better understand wind effects, ESA sponsored the WInd and Salinity Experiment 2000 (WISE-2000) from November 15, 2000, to January 16, 2001, in the Casablanca oil rig, at 40 km off the coast of Tarragona (Spain). This paper is divided into two parts. First, it presents the derived sensitivities of the brightness temperatures at vertical and horizontal polarizations with wind speed, and compares to Hollinger's measurements and numerical simulations. Second, these results are applied to the SMOS sea surface salinity (SSS) retrieval problem for different tracks within the swath. It is shown that, except for low SSS and sea surface temperature (SST), the retrieved SSS has a RMS error of approximately 1 psu in one satellite pass.

[Gabarró, C., M. Vall-llossera, J. Font, and A. Camps, Determination of sea surface salinity and wind speed by L-band microwave radiometry from a fixed platform, *Int. J. Remote Sens.*, 25\(1\): 111-128 \(2004\)](#)

In May 1999, the European Space Agency (ESA) selected SMOS (Soil Moisture and Ocean Salinity) as an Earth Explorer Opportunity mission. One of its goals is the generation of global sea surface salinity (SSS) maps. The satellite sensor is an L-band interferometric radiometer with full-polarimetric capability called MIRAS. The retrieval of SSS from microwave measurements is based on the fact that the brightness temperature (T_b) of seawater is a function of the dielectric constant, temperature and sea surface state (roughness, foam...). The sensitivity of T_b to SSS is maximum at L-band, but it is necessary to quantify the other effects to have reliable SSS retrieval. In order to improve the present understanding of these effects on T_b , ESA sponsored the Wind and Salinity Experiment (WISE) 2000 and 2001 field campaigns. These experimental results are of great importance for the development of sea surface emissivity models that will be used in the future SMOS SSS retrieval algorithms. This paper presents the influence of the emissivity models on the derived SSS from the data obtained in both campaigns. It also presents the impact on the retrieved SSS of using in situ measured or satellite derived wind information, or even simultaneously estimating the wind speed from the measured multi-angular T_b .

[Gabarró, C., J. Font, A. Camps, M. Vall-llossera, and A. Julià, A new empirical model of sea surface microwave emissivity for salinity remote sensing, *Geophys. Res. Lett.*, 31: L01309, doi: 10.1029/2003GL018964 \(2004\)](#)

SMOS (Soil Moisture and Ocean Salinity) is a European Space Agency mission that aims at generating global ocean salinity maps with an accuracy of 0.1 psu, at spatial and temporal resolution suitable for climatic studies. The satellite sensor is an L-band (1400-1427 MHz) aperture synthesis interferometric radiometer. Sea surface salinity (SSS) can be retrieved since the brightness temperature of sea water is dependent on the frequency, angle of observation, dielectric constant of sea water, sea surface temperature and sea surface state. This paper presents a new empirical sea water emissivity model at L-band in which surface roughness effects are parameterized in terms of wind speed and significant wave height. For the SMOS mission these parameters can be obtained from external measurements and model diagnostics. An analysis has been done on the effect on SSS retrieval of different sources for this auxiliary information.

[Camps, A., J. Font, M. Vall-llossera, C. Gabarró, I. Corbella, N. Duffo, F. Torres, S. Blanch, A. Aguasca, R. Villarino, L. Enrique, J. Miranda, J. Arenas, A. Julià, J. Etcheto, V. Caselles, A. Weill, J. Boutin, S. Contardo, R. Niclós, R. Rivas, S. C. Reising, P. Wursteisen, M. Berger, and M. Martín-Neira, The WISE 2000 and 2001 field experiments in support of the SMOS mission: sea surface L-Band brightness temperature observations and their application to sea surface salinity retrieval, *IEEE T. Geosci. Remote*, 42\(4\): 804-823 \(2004\)](#)

Soil Moisture and Ocean Salinity (SMOS) is an Earth Explorer Opportunity Mission from the European Space Agency with a launch date in 2007. Its goal is to produce global maps of soil moisture and ocean salinity variables for climatic studies using a new dual-polarization L-band (1400-1427 MHz) radiometer Microwave Imaging Radiometer by Aperture Synthesis (MIRAS). SMOS will have multiangular observation capability and can be optionally operated in full-polarimetric mode. At this frequency the sensitivity of the brightness temperature (T_b) to the sea surface salinity (SSS) is low: 0.5 K/psu for a sea surface temperature (SST) of 20 degreesC, decreasing to 0.25 K/psu for a SST of 0 degreesC. Since other variables than

SSS influence the Tb signal (sea surface temperature, surface roughness and foam), the accuracy of the SSS measurement will degrade unless these effects are properly accounted for. The main objective of the ESA-sponsored Wind and Salinity Experiment (WISE) field experiments has been the improvement of our understanding of the sea state effects on Tb at different incidence angles and polarizations. This understanding will help to develop and improve sea surface emissivity models to be used in the SMOS SSS retrieval algorithms. This paper summarizes the main results of the WISE field experiments on sea surface emissivity at L-band and its application to a performance study of multiangular sea surface salinity retrieval algorithms. The processing of the data reveals a sensitivity of Tb to wind speed extrapolated at nadir of similar to 0.23-0.25 K/(m/s), increasing at horizontal (H) polarization up to similar to 0.5 K/(m/s), and decreasing at vertical (V) polarization down to similar to -0.2 K/(m/s) at 65° incidence angle. The sensitivity of TB to significant wave height extrapolated to nadir is similar to 1 K/m, increasing at H-polarization up to similar to 1.5 K/m, and decreasing at V-polarization down to -0.5 K/m at 65degrees. A modulation of the instantaneous brightness temperature Tb(t) is found to be correlated with the measured sea surface slope spectra. Peaks in Tb(t) are due to foam, which has allowed estimates of the foam brightness temperature and, taking into account the fractional foam coverage, the foam impact on the sea surface brightness temperature. It is suspected that a small azimuthal modulation similar to 0.2-0.3 K exists for low to moderate wind speeds. However, much larger values (4-5 K peak-to-peak) were registered during a strong storm, which could be due to increased foam. These sensitivities are satisfactorily compared to numerical models and multiangular Tb data have been successfully used to retrieve sea surface salinity.

[Font, J., G. Lagerloef, D. LeVine, A. Camps, and O. Z. Zanifé, The determination of surface salinity with the European SMOS space mission, IEEE T. Geosci. Remote, 42\(10\): 2196-2205 \(2004\)](#)

The European Space Agency Soil Moisture and Ocean Salinity (SMOS) mission aims at obtaining global maps of soil moisture and sea surface salinity from space for large-scale and climatic studies. It uses an L-band (1400-1427 MHz) Microwave Interferometric Radiometer by Aperture Synthesis to measure brightness temperature of the earth's surface at horizontal and vertical polarizations (T-h and T-v). These two parameters will be used together to retrieve the geophysical parameters. The retrieval of salinity is a complex process that requires the knowledge of other environmental information and an accurate processing of the radiometer measurements. Here, we present recent results obtained from several studies and field experiments that were part of the SMOS mission, and highlight the issues still to be solved.

[Etcheto, J., E. Dinnat, J. Boutin, A. Camps, J. L. Miller, S. Contardo, J. Wesson, J. Font, and D. Long, Wind speed effect on L-band brightness temperature inferred from EuroSTARRS and WISE 2001 field experiments, IEEE T. Geosci. Remote, 42\(10\): 2206-2213 \(2004\)](#)

The results from two field experiments in the Mediterranean Sea are used to study the wind speed dependence of brightness temperature at L-band. During the EuroSTARRS airborne experiment, an L-band radiometer made measurements across a large wind speed gradient, enabling us to study this dependence at high wind speed. We compare our results with a two-scale emissivity model using several representations of the sea state spectrum. While the results are encouraging, unfortunately the accuracy of the measurements does not permit us to distinguish between the so-called twice Durden and Vesecky spectrum and the Elfouhaily spectrum above 7 m s⁻¹. The effect of foam is certainly small. During the WISE 2001 field experiment carried on an oil rig, we studied this dependence at low wind speed, finding an abrupt decrease of the wind speed effect on the brightness temperature below 3 m s⁻¹.

A-6. Influència dels factors ambientals sobre organismes i comunitats

[Lefkaditou, E., P. Sánchez, A. Tsangridis, and A. Adamidou, A preliminary investigations on how meteorological changes may affect beach-seine catches of Loligo vulgaris in Thracian Sea \(Eastern Mediterranean\), South African J. of Mar. Sci., 20:453-461 \(1998\)](#)

Daily catches of *Loligo vulgaris* and the fishing effort of commercial beach-seiners operating along the coasts of the Thracian Sea were recorded between October 1994 and May 1995. Taking into account the spatial distribution of the ports, the squid fishing grounds and the daily activity of the beach-seiners, five coastal zones were determined for the monitoring of fishery data. Multivariate analysis failed to show significant differences between the monthly catch rate (cpue) in the zones. However, *Loligo vulgaris* cpue was clearly seasonal, with a distinct peak in November and an evident decline from winter to spring. Temperature, rainfall and local wind records were used in making a preliminary investigation into meteorological factors that may affect beach-seine catches of squid. Multiple linear regression analysis revealed that

temperature is a highly significant explanatory variable for cpue variation, whereas the intensity of the wind plays an important role, but mostly during winter. Rainfall was significantly related to variation in cpue in one zone. Cpue was generally negatively correlated with air temperature and rainfall. Most significant correlations of cpue with wind were also negative.

[Masó, M., A. Sabatés, and M. P. Olivar, Short-term physical and biological variability in the shelf-slope region of the NW Mediterranean during the spring transition period. *Continental Shelf Research*: 661-675 \(1998\)](#)

The present paper reports on temporal mesoscale (weeks) changes in physical and biological coupling in the cross-frontal area off the coast of Catalonia in Spain (NW Mediterranean) during the spring transition period. The effect of short-term physical variability on the spatio-temporal heterogeneity of phytoplankton biomass and in the area of overlap of the larvae of fish species dwelling on the shelf and slope is discussed. Our results indicate that the region off the Catalan coast is a dynamically active area during the spring transition period. Short-term spatio-temporal variability in the frontal system brought about significant changes in the extension of shelf and slope waters, giving rise to major changes in the spatial distribution patterns of chlorophyll and fish larvae. The relationship between integrated chlorophyll, surface chlorophyll and DCM (Deep Chlorophyll Maximum) showed important variability in a short time period. The area of overlap of the larvae of shelf and slope fish species was broad when the front was located offshore, compared to nearly complete segregation of shelf and oceanic fish larvae when the front moved inshore near the coast.

[Rätz, H. J., M. Stein, J. Lloret, Variation in Growth and Recruitment of Atlantic Cod \(*Gadus morhua*\) off Greenland During the Second Half of the 20th. Century, *J. Northwest Atlantic Fisheries Science*, 25, 163-173 \(1999\).](#)

The variation in length-at-ages 4 to 5 years for Atlantic cod (*Gadus morhua*) off Greenland was analysed based on a time series of samples taken from commercial catches comprising 190 000 individual age determinations. Multiple linear regressions revealed significant declines in size for age groups 4 and 5 since the mid-1950s, by 10 and 5 cm, respectively. Growth models accounting for temperature, fishing mortality and stock abundance effects were constructed. Positive temperature and negative fishing mortality effects were found to dominate the variation in length-at-age. The analyses did not indicate a negative effect of stock density on cod growth. During the period 1956–89, the number of recruits at age 3 years was significantly correlated with the spawning stock biomass and June water temperature on top of Fyllas Bank (West Greenland). Both factors positively affected the number of offspring and explained 51% of the observed variation in recruitment.

[Coma, R., M. Ribes, J. M. Gili, and M. Zabala, M, Seasonality in coastal benthic ecosystems. *Trends in Ecology and Evolution* 15:448-453 \(2000\).](#)

For historical reasons, knowledge about seasonality in the dynamics of marine benthic suspension feeders from temperate areas comes mainly from studies of cold temperate seas. Recent surveys of Mediterranean taxa show different patterns from those observed in cold temperate seas, which are characterized by winter dormancy. In the Mediterranean, summer dormancy predominates among taxa and appears to be related to energetic constraints. Temperature and food availability are crucial to the dynamics of benthic suspension feeders. However, because these factors tend to be positively correlated in cold temperate seas, it is difficult to distinguish between their effects. Such correlation does not occur in Mediterranean ecosystems. The contrast between recent studies in the Mediterranean and in other areas can help to disentangle confounded environmental controls.

[Lloret, J., J. Lleonart, and I. Solé, Time series modelling of landings in Northwest Mediterranean Sea. *ICES J. Marine Science*, 57:171-184 \(2000\).](#)

Univariate seasonal ARIMA and intervention models were developed to forecast monthly catches of 53 commercial species in the northwestern Mediterranean Sea, up to one year in advance. In general terms, there was good agreement between forecasts and observed catches of target demersal species. By contrast, models fitted to non-target demersal species and pelagic species were unsatisfactory in terms of explained variability and predicting power. Large commercial size classes were better explained than the small size classes. Intervention analysis was used to identify the significance, magnitude and form of structural shifts (interventions) of the time series for each species. Most of the fitted interventions appeared in small commercial size classes and indicated a decrease in the mean level of the catch. Seasonality of demersal species, caught mainly by trawlers, was mainly attributed to changing availability and recruitment. By contrast, gear type explained the seasonal variation in landings of pelagic and some coastal species. Catch declines of two species were also compared with the variations of their respective seasonal patterns.

[Sabatés, A., J. Salat, and M. P. Olivar, Advection of continental water as an export mechanism for anchovy, *Engraulis encrasicolus*, larvae. *Scientia Marina* 65 \(Suppl. 1\): 77-88 \(2001\)](#)

The presence of a surface layer of a less saline water of continental influence (CIW) along the continental slope off the Catalan coast (NW Mediterranean) was observed in June 1995. This CIW was formed in the Gulf of Lions from Rhône runoff and carried by the current associated with the shelf-slope front. This study analyses the spatio-temporal behaviour of that water of continental influence in relation to the shelf-slope front, and its effect on the distribution of fish larvae, in particular the larvae of the anchovy, *Engraulis encrasicolus*. Displacements of the front are observed to follow an oscillation with a period of eight days and an amplitude of 10 km. Anchovy larvae were associated with the presence of CIW, whereas the oceanic species *Hygophum benoiti* appeared in the region of the slope when the front, and the associated CIW layer, moved close inshore during its oscillation. The size frequency distribution for the anchovy larvae trapped within the CIW suggests that the larvae had been spawned further north, near the Gulf of Lions. It is concluded not only that larvae were transported by the current but also that their development had taken place entirely inside the CIW. The possible benefit to the survival of anchovy larvae of being kept inside that water, though they have been carried far from their spawning areas, is discussed in the basis of fluorescence and microzooplankton data.

[Coma, R., M. Ribes, J. M. Gili, and M. Zabala, Seasonality of in situ respiration rate in three temperate benthic suspension feeders. *Limnol. Oceanogr.* 47:324-331 \(2002\).](#)

Natural respiration rates of suspension feeders in temperate ecosystems are still poorly known. This lack of information constrains our understanding of the functioning and dynamics of benthic marine ecosystems in temperate areas. We examined the in situ seasonal variation in respiration rate of three benthic suspension feeders (a sponge, an ascidian and a gorgonian) in NW Mediterranean sublittoral communities using a recirculating flow respirometry system. The in situ technique is shown to be highly applicable to seasonal studies of the physiological energetics of benthic suspension feeders. Respiration rates of the three species varied two to three folds through the annual cycle, exhibiting a marked seasonal pattern but show no daily cycle, nor significant day-to-day variability within months. Respiration rate of the sponge and ascidian, active suspension feeders, increased with temperature. Respiration rate of the gorgonian, a passive suspension-feeder, did not correlate with temperature. We estimated a Q10 of 1.1, which indicates that respiration rate in this species is not highly dependent on temperature. Synthesis of new tissue of some Mediterranean benthic suspension feeders, such as gorgonians, does not correlate with temperature, allowing us to isolate the effects of temperature and synthesis of new tissue on respiration rate. Synthesis of new tissue increased respiration rate of the gorgonian by approximately 40%. The low rate of synthesis of new tissue during summer, together with the contraction of polyps and the low Q10, explains the low respiration rates of the gorgonian observed during the period of highest temperature. These low respiration rates support the hypothesis that energy limitations may underlie summer dormancy in some benthic suspension-feeding taxa in the Mediterranean.

[Lloret, J., L. Gil de Sola, A. Souplet, and R. Galzin, Effects of large-scale habitat variability on condition of demersal exploited fish in the north-western Mediterranean. *ICES J. Mar. Sci.*, 59:1215-1227 \(2002\).](#)

We examine the variation in condition of ten exploited fish species as an indicator of large-scale habitat quality in the north-western Mediterranean. To determine fish condition, we used morphometric (Fulton's K) and physiological (hepatosomatic, HSI; digestivesomatic, DSI; and gonadosomatic, GSI) indices. Generalized linear models (GLMs) were applied to assess the influence of depth, latitude, length, year, sex and reproductive status on condition. The GLMs incorporating all independent variables accounted for between 25 and 74% of the variance in Fulton's K condition factor, 15-77% of the variance in HSI, 14-35% of the variance in DSI, and 77% of the variance in GSI. The mean condition factor of the species studied showed considerable interannual fluctuations along with an increasing trend over the time series (1994-2001). Length is an important explanatory variable in explaining condition of fish species. Condition typically increased with fish length and explained 72% of the deviance in GSI of *M. barbatus*. For some species, there were differences in condition due to sex and reproductive status, with adults being usually better in condition than juveniles and, among adults, females better than males. The influence of latitude and depth on condition of a given species varied according to the index used to assess condition. When there was a significant effect, fish with the highest condition factor, HSI and/or DSI inhabited the shallowest and northernmost parts of the area of study. Considering that condition influences growth, reproduction and survival of fish, our results support the importance of shallow habitats to productivity of demersal stocks in the Mediterranean Sea.

[Coma, R. and M. Ribes, Seasonal energetic constraints in Mediterranean benthic suspension feeders: effects at different levels of ecological organization, *Oikos*, 101 \(1\): 205-215 \(2003\).](#)

The aim of this work is to examine the role of food as a constraining factor at different levels of ecological organization in

benthic littoral ecosystems. In the search for patterns in ecological systems, it has recently been documented that seasonality in the dynamics of benthic suspension feeders (BSF) in the Mediterranean Sea is characterized by summer dormancy. We review recent studies on seston availability in the water column and feeding and respiration by BSF in the Mediterranean. The objective is to assess whether a pattern across particular studies exists that could provide evidence of food as a constraining factor. A pattern emerges from these organism-level studies, one which indicates the seasonal occurrence of an energy shortage in the taxa exhibiting summer dormancy. This energy shortage is closely related to low food availability and suggests that an energetic constraint underlies the summer dormancy phenomenon. The seasonal occurrence of summer energy shortage also appears to affect the dynamics of BSF at population and community level. In this sense, in late summer 1999, a mass mortality event of BSF affected several hundreds of kilometers in the Ligurian Sea (NW Mediterranean). The fact that the mass mortality event occurred in late summer and especially affected the taxa that exhibit energy shortage – such as anthozoans and sponges – suggests, that energetic constraints may contribute to the understanding of the mass mortality event. The energy shortage phenomenon may provide a mechanism to understand how the occurrence of anomalous climatic conditions may have induced the mass mortality of some BSF taxa. This review points out the existence of a common energy shortage phenomenon mainly related to low food availability as an important determinant of the dynamics of most BSF taxa at organism level in the Mediterranean. But this determinant also affects the dynamics of BSF at population and community level. Therefore, the extant data point up the crucial role of food as a constraining factor for benthic littoral ecosystems in oligotrophic areas like the Mediterranean, with important seasonal variations in seston abundance and composition.

[Olivar, M. P., I. A. Catalán, M. Emelianov, and M. L. Fernández de Puellas, Early stages of *Sardina pilchardus* and environmental anomalies in the North Western Mediterranean, *Estuarine Coastal and Shelf Science*, 56:609-619 \(2003\).](#)

The influence of environmental conditions on the spatial distribution patterns of the early stages of *Sardina pilchardus* off the Catalan coast (Northwestern Mediterranean) during November 1998, February 1999 and November 1999 was investigated. As a general rule, eggs were found on the continental shelf, while larvae displayed a wider cross-shelf distribution. The local circulation during autumn-winter 1998-1999 was dominated by an anticyclonic eddy of new Atlantic Water that remained stationary at the centre of the Catalan Sea from September 1998 to the end of February 1999. Such a situation is very infrequent and the influence of these waters extended to the continental shelf zone, modifying the slope current by diverting the flow and even reversing the direction of the flow. On the third cruise, carried out at the beginning of the spawning season of 1999 (November), the circulation and water mass distribution in the region was typical, with the old Atlantic Water occupying the whole region. Abundance of pilchard eggs and larvae during this last cruise was higher than in the previous surveys. In November 1998, the abundance of pilchard eggs and larvae was relatively low in the zones affected by the new Atlantic Water. The most interesting result of these surveys was the very low concentrations of eggs and larvae found in February 1999, possibly due to the anomalous situation created by the eddy, which had remained almost stationary during the 1998-1999 spawning season.

[Coma, R., E. Pola, M. Ribes, and M. Zabala, Long-term assessment of temperate octocoral mortality patterns, protected vs unprotected areas. *Ecol. Appl.* 14\(5\): 1466-1478 \(2004\).](#)

Coastal marine protected areas (MPA) are usually established with an aim to protect areas of special ecological value. However, protected areas tend to attract more tourism and associated recreational activities, thereby exposing the biota to new risks such as high diving activity. The effects of these drawbacks are still little known for low dynamic systems such as one of the most characteristic and fragile Mediterranean communities, the coralligenous community. Mortality rates were assessed in both heavily dived and lightly dived areas to evaluate the effect of diving on the survival of the gorgonian *Paramuricea clavata*. The study was designed to distinguish man-induced causes from natural causes of gorgonian mortality and to provide criteria for sustainable management of protected areas. We examined total and partial mortality of adult colonies (> 10 cm) at four locations, two of each representing one of the two situations -heavily dived (MPA) and lightly dived (control)-, annually over a 9-year period (1992 -2000). High levels of recreational activity did not affect the degree of injury of the colonies. In average, the proportion of live tissue of the colonies remained steady at about 91 %. Colony death by detachment was the main source of mortality at the MPA, 4 times higher than death due to overgrowth. Mortality rate due to overgrowth remained constant at both areas with an average of 1.2 % y⁻¹. Natural mortality rate in sites with low diving activity was estimated to be about 2.7 % y⁻¹, whereas high diving activity was estimated to increase 3 times the natural mortality rate of the species up to about 7.4 % y⁻¹. The demographic characteristics of long-lived low-turnover structural components of ecosystems makes them especially vulnerable to disturbance events. Since an increase in diving activity seems to be unavoidably brought about by the creation of any MPA, strict regulations of recreational activity must be guaranteed in areas with low turnover communities.

[Lloret, J., I. Palomera, J. Salat, and I. Solé, Impact of freshwater input and wind on landings of](#)

[anchovy \(*Engraulis encrasicolus*\) and sardina \(*Sardina pilchardus*\) in shelf waters surrounding the Ebre River delta \(northwestern Mediterranean\), *Fisheries oceanography*, 13\(2\): 102-110 \(2004\)](#)

Time series analyses (Box-Jenkins models) were used to study the influence of river runoff and wind mixing index on the productivity of the two most abundant species of small pelagic fish exploited in waters surrounding the Ebre (Ebro) River continental shelf (north-western Mediterranean): anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*). River flow and wind were selected because they are known to enhance fertilization and local planktonic production, thus being crucial for the survival of fish larvae. Time series of the two environmental variables and landings of the two species were analysed to extract the trend and seasonality. All series displayed important seasonal and interannual fluctuations. In the long term, landings of anchovy declined while those of sardine increased. At the seasonal scale, landings of anchovy peaked during spring/summer while those of sardine peaked during spring and autumn. Seasonality in landings of anchovy was stronger than in sardine. Concerning the environmental series, monthly average Ebre runoff showed a progressive decline from 1960 until the late 1980s, and the wind mixing index was highest during 1994-96. Within the annual cycle, the minimum river flow occurs from July to October and the wind mixing peaks in winter (December-April, excluding January). The results of the analyses showed a significant correlation between monthly landings of anchovy and freshwater input of the Ebre River during the spawning season of this species (April-August), with a time lag of 12 months. In contrast, monthly landings of sardine were significantly positively correlated with the wind mixing index during the spawning season of this species (November-March), with a lag of 18 months. The results provide evidence of the influence of riverine inputs and wind mixing on the productivity of small pelagic fish in the north-western Mediterranean. The time lags obtained in the relationships stress the importance of river runoff and wind mixing for the early stages of anchovy and sardine, respectively, and their impact on recruitment.

[Sabatés, A., J. Salat, and M. Masó, Spatial heterogeneity of fish larvae across a meandering current in the northwestern Mediterranean. *Deep-Sea Res. I*, 51: 545-557 \(2004\)](#)

Physical and biological coupling in frontal zones presents a high spatio-temporal variability as a result of both the hydrographic complexity of such systems and the biological activity of the organisms. A permanent frontal system (density front and associated current), parallel to the bathymetry, is present in the shelf-slope region in the Catalan Sea (NW Mediterranean). This study presents the results obtained from a detailed examination of the frontal system and larval fish distribution in a small area in the Catalan Sea, over the span of just a few days. The shelf-slope front presented a meandering structure with a wavelength of about 50-60 km and an amplitude of about 10-12 km. The position of the frontal system on successive transects was shifting gradually, from quite close to the edge of the shelf to about 10 km towards the open sea. This shift may reflect a frontal oscillation due to the passage of a half wave of a meander. During the phase in which the front draws nearer to the shelf, slope to shelf exchanges take place, with fish larvae accumulating on the coastal side of the front along with very low concentrations from there oceanwards. During the phase in which the front moves away from the shelf, shelf to slope exchanges take place, and fish larvae were beginning to be dispersed so that high larval concentrations were shifted in an oceanwards direction. While there were still relative accumulations on the coastal side of the front, these accumulations were not nearly as pronounced. On that occasion there was heightened upwelling on the oceanic side of the front with local peaks in chlorophyll biomass in this region. The results presented here have revealed not only that the fertilization mechanisms are associated with the front but have also shown that oscillations in the front have a decisive role in supplying nutrients to the photic zone on an intermittent basis. The temporal scale at which the frontal system oscillates also exerts a decisive influence on processes affecting concentration/dispersal of larval fish populations.

[Alemany, F., S. Deudero, B. Morales-Nin, J. L. López-Jurado, M. Palmer, and I. Palomera, Influence of physical environmental factors on the composition and horizontal distribution of summer larval fish assemblages off Mallorca island \(Balearic archipelago, Western Mediterranean\), *J. Plankton Research*, 28 \(5\): 473-487 \(2006\)](#)

Two ichthyoplankton surveys were carried out in two areas off Mallorca island (Balearic archipelago, western Mediterranean) in June 1996 and August 1996, respectively. The aim of both surveys was to assess the influence of physical environmental factors on the horizontal distribution of larval fish assemblages, focusing on larvae of large migratory pelagic fish species. Canonical correspondence analysis (CCA) indicated that in the June survey, the patterns of horizontal distribution of fish larvae were mainly conditioned by depth and by the distribution of two surface water masses: the Modified Atlantic Waters (MAW), of recent Atlantic origin, and the older Surface Mediterranean Waters (SMW). The effect of depth gradient was clear in mesopelagic and neritic species, but it was not so evident in the larvae of large pelagic species which presented a highly patchy distribution. Contrastingly, the August patterns of horizontal fish larvae distribution were significantly correlated with the surface salinity gradient resulting from successive MAW inflows, whereas depth did not show any significant effect, probably linked to the bottom topography with a very narrow shelf area. The data obtained highlight that the Balearic Islands constitute an important spawning ground for most of the large pelagic fishes inhabiting Mediterranean waters, both highly migratory and resident species.

[Catalán, I. A., M. P. Olivar, I. Palomera, and E. Berdalet, Link between environmental anomalies, growth and condition of pilchard *Sardina pilchardus* \(Walbaum\) larvae in the NW Mediterranean, *Mar. Ecol. Progr. Ser.*, 307: 219-231 \(2006\)](#)

Relationships between environmental factors and the growth and condition of pilchard *Sardina pilchardus* (Walbaum) larvae were studied in November 1998 in the northwestern Mediterranean (NWM). Long-term growth of fish was assessed using otolith analysis and condition was assessed through histological and biochemical (RNA/DNA) indices. These measurements were conducted on larvae belonging to 2 station groups (A and B) previously defined through principal component analysis (PCA) on 7 environmental variables. Correlations between individual condition indices and environmental values at place of capture were also performed. Condition in environmental group A was significantly higher than in group B as assessed by both histological indices and RNA/DNA. Long-term growth, however, did not differ significantly between groups except for the otolith diameter vs. standard length (SL) relationship. The stations conforming to environmental group A were characterised by environmental ranges that would form a favorable habitat for larval success, including surface temperatures < 19 °C, relatively low stratification (maximum Brunt Vaissala, B-V, < 0.8 cycles; h⁻¹) and mean potential food abundance > 4500 nauplii N m⁻³ or > 5500 of other microzooplankters T-N m⁻³. Apart from the good agreement found between histological and RNA/DNA results, each approach offered different information: histological indices detected the largest portion of unfit larvae at size-ranges ≤ 8 mm, whereas RNA/DNA best discriminated large larvae. The results from this study support the view that links exist between mesoscale anomalies, spawning intensity and growth or condition of pilchard larvae in the NWM.

[Coma, R., C. Linares, M. Ribes, D. Díaz, J. Garrabou, and E. Ballesteros, Consequences of a mass mortality event on populations of the gorgonian *Eunicella singularis* \(Cnidaria: Octocorallia\) in Menorca \(Balearic Islands, NW Mediterranean\). *Mar. Ecol. Prog. Ser.* 327:51-60 \(2006\).](#)

At the end of the boreal summer of 1999, many invertebrates in hard-bottom communities in the NW Mediterranean Sea suffered an episode of mass mortality. Our study examined the effects of this event on populations of the temperate octocoral *Eunicella singularis* at Menorca (Balearic Islands). The event affected colonies over the entire depth range where the species is present (15 to 40 m). Four years after the occurrence of the event, 59% of the colonies still exhibited some damage. The extent of injury of the colonies varied among locations, ranging between 37 and 67% with a mean of 50% of the colony surface. The proportion of dead colonies also varied among locations from 26 to 62%, with an overall mean of 46% of the population. The proportion of dead colonies was inversely correlated with density. Current size distribution of the colonies indicated the occurrence of low recruitment during the years subsequent to the mass mortality event. Our study demonstrates that the 1999 mass mortality event was geographically more extensive than previously thought (Menorca is located about 400 to 700 km from areas where mass mortality was previously reported, along the coast of Provence and Liguria). The mortality rate of *E. singularis* estimated for the Menorca populations was the highest value recorded to date for this species, showing that the delayed effects of the mortality event exerted a much greater impact on these populations than the immediate effects. Additional impacts result from a reduction in recruitment. These delayed consequences may lead to important changes in community composition, structure, processes and function, as gorgonians are key structural and functional organisms within these communities.

[Cox, E. F., M. Ribes, and R. A. Kinzie III, Temporal and spatial scaling of planktonic responses to nutrient inputs into a subtropical embayment. *Mar. Ecol. Prog. Ser.* 324: 19-35 \(2006\).](#)

We carried out a study of the spatial and temporal effects of land-derived material on water column nutrients and plankton dynamics in a subtropical estuary. The study had 2 parts: (1) a 3 yr synoptic monitoring program, and (2) a shorter 1.5 yr study during the second half of the program, which focused on individual pulses driven by discrete rainfall events. Although we found spatial differences in some water column parameters within Ka^{ne} Bay and an adjacent oceanic site, inorganic nutrient levels were generally comparable in the Bay and offshore. One difference was that *Prochlorococcus* spp. numerically dominated the plankton at the oceanic site whereas *Synechococcus* spp. dominated at all Bay sites. The switch in dominance appears to be due to light characteristics and dissolved organic nitrogen (DON), but not dissolved inorganic nutrient availability. There were no annual cycles in water column parameters within the Bay; however, a comparison of dry and wet seasons did show some differences. Planktonic cell abundance was in general lower during the wet season, with the exception of opportunistic diatoms that were more abundant during the wet season. A drought during the study period may have influenced our results. Pulses were characterized by an elevation in inorganic nutrient concentrations in the Bay close to the stream mouth. The general response was an increase in abundance of microphytoplankton and chl a after a 3 to 6 d lag following the nutrient increase. Picophytoplankton showed an increase in fluorescence per cell after a 12 to 24 h lag, probably related to a decrease in irradiance associated with turbidity in runoff. The Bay can act as source of dissolved inorganic nutrients and plankton for oceanic waters; however, planktonic populations in the Bay are primarily autochthonous and do not represent an oceanic source of nutrients for plankton consumers within Ka^{ne} Bay.

[Guadayol, Ò., and F. Peters, Analysis of wind events in a coastal area: a tool for assessing turbulence variability for studies on plankton. *Scientia Marina*. 70: 9-20 \(2006\).](#)

Turbulence at different scales, from generation to dissipation, influences planktonic communities. Many experimental studies have recently been done to determine the effects of small-scale turbulence on plankton, but it is difficult to state the relevance of the findings since there is little unbiased information on turbulence variability in the sea. In this study, we use wind velocity data series from several meteorological stations located along the Catalan coast to estimate the spatial and temporal variability of small-scale turbulence in the upper ocean. Using a peaks-over-threshold approach, we develop a statistical model to assess frequency of wind events, as a function of their persistence and intensity. This model shows higher frequencies of intense events in locations and seasons with higher mean wind values. Finally, the wind speed data series are converted into turbulent energy dissipation rate estimates at 1 m depth to determine the general distribution of turbulence in the Catalan coast. Geographical variability is larger than seasonal in frequency and persistence of wind events, owing to differences in local relief. These statistical models developed for wind events combined with empirical relationships between wind and turbulence, are tools to estimate the occurrence and persistence of turbulent events at a given location and season. They serve to put past, present and future studies of the effects of turbulence on coastal planktonic organisms and processes into context.

[Pelegrí, J. L., A. Marrero-Díaz, and A. W. Ratsimandresy, Nutrient irrigation of the North Atlantic, *Progress in Oceanography*, 70, 366-406. \(2006\)](#)

The North Atlantic, as all major oceans, has a remarkable duality in primary production, manifested by the existence of well-defined high and low mean primary production regions. The largest region is the North Atlantic Subtropical Gyre (NASTG), an anticyclone characterized by bowl shaped isopycnals and low production. The NASTG is surrounded at its margins by smaller cyclonic high-production regions, where these isopycnals approach the sea surface. The most extensive cyclonic regions are those at the latitudinal extremes, i.e. the subpolar and tropical oceans, though smaller ones do occur at the zonal boundaries. In this article we review historical data and present new analyses of climatological data and a selected number of hydrographic cruises in the western/northwestern and eastern/southeastern boundaries of the NASTG, with the objective of investigating the importance of upward epipychnal advection of nutrient-rich subsurface layers (irrigation) in maintaining high primary production in the euphotic layers. In the North Atlantic Subpolar Gyre (NASPG) irrigation implies intergyre exchange caused by the outcropping extension of the Gulf Stream (GS), following the formation of the deep winter mixed-layer. In the eastern boundary of the NASTG irrigation is attained through a permanent upwelling cell, which feeds the Canary Upwelling Current (CUC). In the southeastern corner irrigation occurs in fall, when the Guinea Dome (GD) is reinforced, and in winter, when the CUC reaches its southernmost extension. Other characteristics of the north/south extension of the GS/CUC are the seasonal nutrient replenishing of subsurface layers (spring restratification of NASPG and winter relaxation of the GD) and the maintenance of high levels of diapycnal mixing during the last phase of nutrient transfer to the euphotic layers. Off the Mid-Atlantic Bight the GS transports a total of about 700 kmol s^{-1} of nitrate, with almost 100 kmol s^{-1} carried in the surface ($\sigma_\theta < 26.8$) layers and some 350 kmol s^{-1} in the intermediate ($26.8 < \sigma_\theta < 27.5$) layers. A box model suggests that north of Cape Hatteras most surface and upper-thermocline nitrates are used to sustain the high levels of primary production in the NASPG. Off Cape Blanc there is winter along-shore convergence of order 10 kmol s^{-1} of nitrate in the near-surface layers (possibly larger in summer), with only a small fraction used to sustain local primary production in the coastal upwelling band and the remainder carried to the interior ocean. Nutrients and biomass exported from these cyclonic regions may account for the concentration levels observed within the NASTG.

[Sabatés, A., P. Martín, J. Lloret, and V. Raya, Sea warming and fish distribution: the case of the small pelagic fish, *Sardinella aurita*, in the western Mediterranean. *Global Change Biol*. 12: 2209-2219 \(2006\)](#)

This study analyses the temporal and spatial changes in abundance and distribution of the warm water species round sardinella (*Sardinella aurita*) in the western Mediterranean over the last decades in relation to sea water temperature. In the western Mediterranean basin (1950–2003), a significant positive relationship was found between round sardinella landings and temperature anomalies. Along a latitudinal gradient off the Mediterranean Iberian coast (1989–2004), a gradual increase in species abundance was observed from south to north, with a certain time lag going northwards, associated with the increase in sea water temperature. The abundance of round sardinella in the two warmest and southernmost areas was positively and significantly correlated with sea surface temperature registered during the start of gonad maturation the previous year. In addition, the positive relationship established between water temperature and abundance of round sardinella in the coldest and northernmost study area demonstrates that there is a temperature limit for the distribution of this species in the western Mediterranean. In addition, this study analyses round sardinella larvae distribution and abundance in the summers of 2003 and 2004, and conducts a comparison with the situation 20 years ago (summer 1983). Results show a marked increase in larval abundance during the last decades and the present appearance of larvae in the

northernmost study areas, where they did not occur 20 years ago. This indicates the successful reproduction of round sardinella in the northern part of the Mediterranean, where the species has expanded, confirming its establishment in the area.

[Ribes, M., and M. J. Atkinson, Effects of water velocity on picoplankton uptake by coral reef communities. Coral Reefs, \(2007\)](#)

Abstract In previous experiments, rates of picoplankton uptake into coral communities were controlled by sponge and ascidian biomass. Those experimental communities, however, had relatively few sponges and ascidians. In contrast, turbulent transport of particles into the momentum boundary layers can limit particle removal by layered, dense bivalve populations. In this study, the role of water velocity in controlling particulate nutrient-uptake by rubble communities was evaluated, in which the rubble was more completely covered by sponges and ascidians. Picoplankton uptake was proportional to concentration over a range of cell concentrations from $3.0 \cdot 10^5$ to $9.5 \cdot 10^5$ heterotrophic bacteria ml⁻¹, $4.1 \cdot 10^4$ to $1.2 \cdot 10^5$ *Synechococcus* sp. ml⁻¹ and $6.3 \cdot 10^3$ to $1.8 \cdot 10^4$ picoeukaryotes ml⁻¹. The first-order uptake rate constants, normalized to sponge and ascidian biomass, were similar to previous experimental communities. Picoplankton uptake increased 1.6-fold over a 7-fold change in water velocity, 0.05–0.35 m s⁻¹. This increase has been interpreted as a result of higher turbulent transport within the rough coral community (canopy), as indicated by a 1.6-fold increase in the bottom friction with increasing water velocity.

[Sabatés, A., M. P. Olivar, J. Salat, I. Palomera, and F. Alemany, Physical and biological processes controlling the distribution of fish larvae in the NW Mediterranean. Progress Oceanogr., 73 \(2007\)](#)

The Mediterranean is globally considered an oligotrophic sea. However, there are some places or certain seasons in which mechanisms that enhance fertility may occur. These mechanisms and related processes are especially relevant when they take place during the period of larval development. This study analyzes how environmental conditions occurring in the NW Mediterranean, at local and seasonal scales, contribute to determine the temporal and spatial patterns of fish reproductive activity in the region. The structure of the bathymetry, types of bottoms, diversity of adult fish habitats, as well as mechanisms conditioning the primary production of the region determine the location of spawning, whereas physical processes (eg. shelf-slope density front and associated current, continental water inflows, winter mixing, stratification of the water column) determine the final distribution patterns of fish eggs and larvae. High larval concentrations occur over the edge of the continental shelf in relation to the presence of the shelf-slope front and its associated convergence. However, this pattern is subject to considerable spatio-temporal variability, due to frontal mesoscale activity. High larval abundance can also be observed near the coast in zones with topographic irregularities that can greatly modify circulation favouring penetration of slope waters into the shelf. Finally, larvae of large pelagic migratory species are mainly distributed in areas under the influence of recent Atlantic Water (AW) and near the frontal system between these inflowing AW and the more saline waters of the northern basin. A pronounced seasonal variability regarding both the number of species and the number of fish larvae in the plankton can be observed throughout the year. The two dominant species, sardine and anchovy, have non-overlapping spawning periods, autumn-winter and spring-summer, respectively. The diversity of feeding patterns as well as the fact that different fish species have different spawning periods might reduce inter and intra-specific competition for food resources in this area. Most NW Mediterranean fish reproduce during the spring-summer stratification period, when the phytoplankton biomass values at the upper layers of the water column are lower than in winter. The development of the Deep Chlorophyll Maximum in this period and the high zooplankton biomass associated to it offers an important food source for the larvae. Additionally, during this period the inputs of continental waters in certain areas are one of the fertilization mechanisms of surface waters and some species, as anchovy, takes advantage of this situation. Autumn-winter is the period with lower ichthyoplankton diversity, being dominated by sardine, which reproduces on the continental shelf. The mixing of the water column during winter is one of the mechanisms that enhances productivity on continental shelves. Moreover, there are not intense currents on the shelf and the circulation is usually anticyclonic, favouring larval retention in this zone. Fish species show reproductive strategies and larval fish behaviour that allow them to take advantage of the available resources throughout the seasonal cycle. These strategies, together with the high ecological efficiency of oligotrophic systems, contribute to the relatively high yield of Mediterranean fisheries.

[Sabatés, A., J. Salat, I. Palomera, M. Emelianov, M. L. Fernández de Puelles, and M. P. Olivar, Advection of anchovy larvae along the Catalan continental slope \(NW Mediterranean\). Fish. Oceanogr. 16: 130-141 \(2007\)](#)

The Gulf of Lions is one of the main anchovy (*Engraulis encrasicolus*) spawning areas in the NW Mediterranean. During the spring, low-salinity surface water from the outflow of the Rhône is advected by the shelf-slope current along the continental slope off the Catalan coast. In June 2000, a Lagrangian experiment tracking these low-salinity surface waters was conducted to assess the importance of this transport mechanism for anchovy larvae and to determine the suitability of the tracked surface waters for survival of anchovy larvae. Anchovy larvae from the spawning area in the Gulf of Lions were

advected towards the south in the low salinity waters. The size increase of anchovy larvae throughout the Lagrangian tracking closely followed the general growth rate calculated by otolith analysis (0.65 mm day⁻¹). However, advection by the current was not the only mechanism of anchovy larval transport. A series of anticyclonic eddies, originated in the Gulf of Lions and advected southwards, seemed to play a complementary role in the transport of larvae from the spawning ground towards the nursery areas. These eddies not only contributed to larval transport but also prevented their dispersion. These transport and aggregation mechanisms may be important for anchovy populations along the Catalan coast and require further study.

A-7. Biogeoquímica del clima

[Simó, R., and C. Pedrós-Alió, Short-term variability in the open ocean cycling of dimethylsulfide. *Global Biogeochemical Cycles* 13: 1173-1181 \(1999\).](#)

The marine biogeochemical cycle of dimethylsulfide (DMS), the main natural source of sulfur to the global atmosphere, was studied during a 2-week Lagrangian experiment in the subpolar North Atlantic, at 60°N 21°W. A bloom of coccolithophores, mostly of the species *Emiliania huxleyi*, dominated the phytoplankton assemblage over the first week. High surface concentrations of dimethylsulfoniopropionate (DMSP, 37-70 nM) were found along with moderate DMS concentrations (3-9 nM) during the entire experiment. Rates of biological DMSP consumption (8-51 nM d⁻¹) and DMS production (1-14 nM d⁻¹) and consumption (0-6 nM d⁻¹) were measured in short-term dark incubations of surface seawater. Rates of DMSP biosynthesis (11-31 nM d⁻¹) and DMS photochemical loss (1-10 nM d⁻¹) were estimated by budgeting concentrations and transformation rates between Lagrangian samplings. Air-sea exchange rates for DMS (0.03-3 nM d⁻¹) were calculated from surface concentrations, seawater temperature, and wind speed. All major processes involved in the DMS cycle showed significant short-term variability in coupling to the variability of solar radiation, wind speed, and mixing. Biotic and abiotic DMS turnover rates were of similar magnitude and very dynamic, with a prompt response to a rapidly changing physical environment. The rapid impact of meteorological forcing factors on DMS cycling provides the basis for a sulfur-mediated, short-term plankton/climate interaction.

[Simó, R., and C. Pedrós-Alió, Role of vertical mixing in controlling the oceanic production of dimethyl sulphide. *Nature* 402: 396-399 \(1999\).](#)

Marine microbiota plays a key role in the global biogeochemical sulphur cycle by making possible the transference of reduced sulphur from the oceans to the atmosphere in the form of dimethyl sulphide (DMS). Oxidation of DMS to acidic aerosols has an effect on particle nucleation and growth over the oceans, and, thereby, has a potential effect on the radiative balance and global climate. Testing whether this constitutes a self-regulated plankton-climate interaction has remained elusive, essentially because little is known of the feedback effects of climate on the marine DMS cycle. DMS is produced by enzymatic cleavage of the abundant algal component dimethylsulphoniopropionate (DMSP). Despite the high potential for DMS generation in the ocean, actual DMS production is tempered by the relative contribution of the cleavage pathway over non-DMS producing, DMSP utilisation processes in the food web. What controls this contribution is unknown. Here we present data of DMSP consumption, DMS production and mixing depths in the subpolar North Atlantic, compare them with published data from other latitudes, and show evidence for a profound impact of mixed layer depth on DMS yield in the short term. This, along with the seasonal effect of vertical mixing on plankton succession and food web structure, suggests that climate-derived mixing controls DMS production over vast regions of the oceans.

[Simó, R., Production of atmospheric sulfur by oceanic plankton: biogeochemical, ecological and evolutionary links. *Trends in Ecology and Evolution* 16: 287-294 \(2001\).](#)

Biological production of the volatile compound dimethylsulfide in the ocean is the main natural source of tropospheric sulfur on a global scale, with important consequences for the radiative balance of the Earth. In the late 1980s, a Gaian feedback link between marine phytoplankton and climate through the release of atmospheric sulfur was hypothesized. But the idea of microalgae producing a substance that could regulate climate has been criticized on the basis of its evolutionary feasibility. Recent advances have shown that volatile sulfur results from ecological interactions and transformation processes through planktonic food webs. It is, therefore, not only phytoplankton biomass, taxonomy or activity, but food-web structure and dynamics that drive the oceanic production of atmospheric sulfur. Accordingly, the viewpoint on the ecological and evolutionary bases of this amazing marine biota – atmosphere link is changing.

[Simó, R., and J. Dachs, Global ocean emission of dimethylsulfide predicted from biogeophysical data.](#)

[Global Biogeochemical Cycles 16: 1078, doi: 10.1029/2001GB001829 \(2002\).](#)

Among the biosphere-atmosphere interactions that influence climate, the emission of dimethylsulfide (DMS) from the ocean plays a prominent role for its high potential in cloud albedo regulation. In order to advance in our understanding and quantification of this coupled ocean-atmosphere system, both synoptic and predictive capabilities must be largely improved. Hitherto, large-scale oceanic DMS has eluded being captured from remote sensing, correlated with synoptic variables, or simulated by mechanistic modeling. We have found a simple empirical relationship that permits global-ocean monthly distributions of DMS concentration to be computed from a combination of remotely sensed biospheric data (chlorophyll a) and climatological geophysical data (mixed layer depth). This relationship allows for the desired synopticity and predictability in the ocean-to-atmosphere sulfur flux, which we have globally quantified as 23-35 Tg S y⁻¹. Also, our algorithm stands in support of a biogenic-DMS/solar-radiation negative feedback and opens the door towards quantifying its strength and its response to global warming.

[Pedrós-Alió, C., and R. Simó, Studying marine microorganisms from space. International Microbiology, doi 10.1007/s10123-002-0087-7 \(2002\).](#)

The title "Studying marine microorganisms from space" may appear to be an oxymoron: microbes are but a few micrometers in diameter and are not visible to the naked eye, how can they be observed from space? The answer resides in the large numbers of microorganisms present in the sea and in the global impact of their activities. Here we will present a few examples of how microorganisms can be studied from satellites. The first case will be the best known: the main pigment of all photosynthetic microbes (chlorophyll a) can be determined from satellites. These kinds of studies have contributed a tremendous amount of understanding about the distribution and dynamics of primary production in the oceans. Two other examples will concern analysis of heterotrophic prokaryotic production and estimates of dimethyl sulfide (DMS) concentration and flux to the atmosphere. These three processes are of fundamental importance for the functioning of the biosphere. Marine microbes carry out about half of the total primary production in the planet. A substantial fraction of the respiration in the oceans is due to the activity of heterotrophic prokaryotes. Finally, the flux of DMS to the atmosphere is believed to constitute one of the mechanisms by which the biota can regulate climate. The global implications of microbial processes in the oceans can only be addressed with the help of satellites.

[Gabric, A., R. Simó, R. Cropp, T. Hirst, and J. Dachs, Global estimates of the oceanic emission of DMS under enhanced greenhouse conditions. Global Biogeochemical Cycles 18, GB2014, doi:10.1029/2003GB002183 \(2004\).](#)

We have used a marine food-web model, an atmosphere-ocean general circulation model (GCM), and an empirical dimethylsulfide (DMS) algorithm to predict the DMS seawater concentration and the DMS sea-to-air flux in 10° latitude bands from 70°N to 70°S under contemporary and enhanced greenhouse conditions. The DMS empirical algorithm utilizes the food-web model predictions of surface chlorophyll and the GCM's simulation of oceanic mixed layer depth. The food-web model was first calibrated to contemporary climate conditions using satellite-derived chlorophyll data and meteorological forcings. For the climate change simulations, the meteorological forcings were derived from a transient simulation of the CSIRO Mark 2 GCM, using the IPCC/IS92a radiative forcing scenario to the period of equivalent CO₂ tripling (2080). The globally integrated DMS flux perturbation is predicted to be +14%; however, we found strong latitudinal variation in the perturbation. The greatest perturbation to DMS flux is simulated at high latitudes in both hemispheres, with little change predicted in the tropics and sub-tropics. The largest change in annual integrated flux (+106%) is simulated in the Southern Hemisphere between 50°S and 60°S. At this latitude, the DMS flux perturbation is most influenced by the GCM-simulated changes in the mixed layer depth. The results indicate that future increases in stratification in the polar oceans will play a critical role in the DMS cycle and climate change.

[Jurado, E., R. Lohmann, K. C. Jones, R. Simó, and J. Dachs, Atmospheric deposition of persistent organic pollutants to the Atlantic and inferences for the global oceans. Environmental Science & Technology 38: 5505-5513 \(2004\).](#)

Atmospheric deposition to the oceans is a key process affecting the global dynamics and sinks of persistent organic pollutants (POPs). A new methodology that combines aerosol remote sensing measurements with measured POP aerosol-phase concentrations is presented to derive dry particulate depositional fluxes of POPs to the oceans. These fluxes are compared with those due to diffusive air-water exchange. For all polychlorinated biphenyl (PCB) congeners and lower chlorinated dibenzo-p-dioxins and furans (PCDD/Fs), air-water exchange dominates the dry deposition mechanism. However, this tendency reverses in some areas, such as in marine aerosol influenced areas and dust outflow regions, consistent with the important variability encountered for the depositional fluxes. Seasonal variability is mainly found in mid-high latitudes, due to the important influence of wind speed enhancing dry deposition fluxes and temperature as a driver of the gas particle partitioning of POPs. The average dry aerosol deposition flux of ^aPCBs and ^aPCDD/Fs to the

Atlantic Ocean is calculated to be in the order of $66 \text{ ng m}^{-2} \text{ yr}^{-1}$ and $9 \text{ ng m}^{-2} \text{ yr}^{-1}$ respectively. The total dry aerosol deposition of aPCBs and aPCDD/Fs to the Atlantic Ocean is estimated to be 2200 kg yr^{-1} and 500 kg yr^{-1} , respectively, while the net air-water exchange is higher, $22000 \text{ kg aPCBs yr}^{-1}$ for PCBs and $1300 \text{ kg aPCDD/Fs yr}^{-1}$. Furthermore, it is suggested that marine aerosol plays an important role in scavenging atmospheric contaminants.

[Simó, R., From cells to globe: approaching the dynamics of DMS\(P\) in the ocean at multiple scales. Canadian Journal of Fisheries and Aquatic Sciences 61\(5\): 673-684 \(2004\).](#)

Major advances in dimethylated sulfur research are being made thanks to approaching its dynamics at multiple scales. At the molecular-to-cellular level, single-cell techniques in molecular biology allow us identify the microbes involved in cycling of dimethylated sulfur. Also, we find that dimethylsulfoxide (DMSO) is as ubiquitous as dimethylsulfoniopropionate (DMSP) in marine plankton, which supports the recent suggestion that both compounds are involved in coping with oxidative stress. At the community level, there is recent evidence for the role of DMSP as a major carrier in organic sulfur transfer and cycling through trophic levels, from phytoplankton to bacteria and to zooplankton through herbivore protozoans. As a consequence, the food-web dynamics drives the oceanic emission of atmospheric sulfur. At the ecosystem level, the diverse and intricate effects of the physicochemical setting (light, wind, nutrients) on the oceanic cycling of dimethylated sulfur are being uncovered. A proposed shortcut to detailed understanding of the individual processes presents the depth of the surface mixed layer as the variable that integrates most of the environmental effects and serves for predicting dimethylsulfide (DMS) concentrations, even at the global ocean level. This opens the door to assessing the strength of the DMS biogeochemical system as a climate regulator.

[Jurado, E., F. Jaward, K. C. Jones, R. Simó, and J. Dachs, Wet deposition of persistent organic pollutants to the global oceans. Environmental Science & Technology 39 : 2426-2435 \(2005\).](#)

Wet deposition fluxes of polychlorinated biphenyls and polychlorinated dibenzo-p-dioxins and furans to the Atlantic Ocean have been estimated by combining meteorological satellite data and measured atmospheric field concentrations. They are then compared to other atmospheric depositional mechanisms on a global scale. Additional features not treated in traditional studies are addressed such as contaminant adsorption onto raindrops and enhancement of dry gaseous diffusive fluxes due to rain induced turbulence. Wet deposition estimates show a high spatial and seasonal variability, with maxima located in the Intertropical Convergence Zone (ITCZ) and in low temperature regions. Seasonal variability reflects the northward shift of ITCZ in July. Average wet deposition fluxes estimated for the Atlantic Ocean in this study are 110 and $45 \text{ ng m}^{-2} \text{ yr}^{-1}$ for aPCB and aPCDD/Fs , respectively. Furthermore, the total wet deposition to the Atlantic results in 4100 kg yr^{-1} (aPCB) and 2500 kg yr^{-1} (aPCDD/Fs). Model validation shows good agreement with available coastal data measurements of wet deposition fluxes. When compared to other atmospheric depositional mechanisms and during precipitation events, wet deposition is found to be dominant. However, when raining events and non-raining time periods are integrated, air water diffusive exchange fluxes acquire an important role, which can be dominant in some regions and for some POPs.

[Moran, X.A.G., M. Sebastian, C. Pedrós-Alió, and M. Estrada, Response of Southern Ocean phytoplankton and bacterioplankton production to short- term experimental warming. Limnol. Oceanogr. 51: 1791-1800 \(2006\).](#)

We examined the potential response of Southern Ocean pelagic ecosystems to warming through changes in total primary production (particulate plus dissolved $5 \text{ PPP} + \text{DPP}$) and bacterial production (BP), determined simultaneously at ambient temperature (21.4 to 0.4uC) and at 2uC in eight experiments performed near the Antarctic Peninsula in late spring 2002. Short (6 h) time course experiments of radiocarbon uptake and photosynthesis–irradiance relationships consistently showed that a significant amount of photosynthate appeared as dissolved substances, with a mean 35% extracellular release (PER). Whereas PPP remained virtually unchanged ($0.7 \text{ mg C m}^{-2} \text{ h}^{-1}$), DPP increased significantly at 2uC from 0.5 to $0.9 \text{ mg C m}^{-2} \text{ h}^{-1}$. The corresponding increase in PER (54% on average) was significantly and positively correlated with the temperature difference among treatments, suggesting that an increase in DPP could be expected with a temperature rise in the Southern Ocean. BP, estimated via $[3\text{H}]$ leucine incorporation, tended to increase at 2uC only at low absolute values, and this increment was inversely related to PPP. However, our results show that the estimated bacterial carbon demand (BCD) was generally well below concurrent DPP at both treatments (mean BCD:DPP ratios of 0.60 and 0.27 at ambient temperature and 2uC , respectively), indicating that temperature-related extra inputs of organic substrates were not fully and immediately processed by bacteria. To the extent that these results reflect general ecophysiological trends, warming of Southern Ocean surface waters could produce changes in plankton-mediated biogeochemical processes leading to a greater importance of dissolved organic matter fluxes.

[Vallina, S. M., R. Simó, and S. Gassó, What controls CCN seasonality in the Southern Ocean? A statistical analysis based on satellite-derived chlorophyll and CCN and model-estimated OH radical and](#)

[rainfall. *Global Biogeochemical Cycles* 20, GB1014, doi: 10.1029/2005GB002597 \(2006\).](#)

A 3-year time series set (from January 2002 to December 2004) of monthly means of satellite-derived chlorophyll (CHL) and cloud condensation nuclei (CCN), as well as model outputs of hydroxyl radical (OH), rainfall amount (RAIN), and wind speed (WIND) for the Southern Ocean (SO, 40°S–60°S) is analyzed in order to explain CCN seasonality. Chlorophyll is used as a proxy for oceanic dimethylsulfide (DMS) emissions since both climatological aqueous DMS and atmospheric methanesulfonate (MSA) concentrations are tightly coupled with chlorophyll seasonality over the Southern Ocean. OH is included as the main atmospheric oxidant of DMS to produce CCN, and rainfall amount as the main loss factor for CCN through aerosol scavenging. Wind speed is used as a proxy for sea salt (SS) particles production. The CCN concentration seasonality is characterized by a clear pattern of higher values during austral summer and lower values during austral winter. Linear and multiple regression analyses reveal high significant correlations between CCN and the product of chlorophyll and OH (in phase) and rainfall amount (in antiphase). Also, CCN concentrations are anticorrelated with wind speed, which shows very little variability and a slight wintertime increase, in agreement with the sea salt seasonality reported in the literature. Finally, the fraction of the total aerosol optical depth contributed by small particles (ETA) exhibits a seasonality with a 3.5-fold increase from austral winter to austral summer. The biogenic contribution to CCN is estimated to vary between 35% (winter) and 80% (summer). Sea salt particles, although contributing an important fraction of the CCN burden, do not play a role in controlling CCN seasonality over the SO. These findings support the central role of biogenic DMS emissions in controlling not only the number but also the variability of CCN over the remote ocean.

[Vila-Costa, M., R. Simó, H. Harada, J. M. Gasol, D. Slezak, and R. P. Kiene, *Dimethylsulfoniopropionate uptake by marine phytoplankton. *Science* 314: 652-654 \(2006\).*](#)

Dimethylsulfoniopropionate (DMSP) accounts for most of the organic sulfur fluxes from primary to secondary producers in marine microbial food-webs. Incubations of natural communities and axenic cultures with radio-labeled DMSP showed that dominant phytoplankton groups of the ocean: the unicellular cyanobacteria *Prochlorococcus* and *Synechococcus*, and diatoms, as well as heterotrophic bacteria take up and assimilate DMSP-sulfur, thus diverting a proportion of plankton-produced organic sulfur from emission into the atmosphere.

[Vázquez-Domínguez, E., D. Vaqué, and J. M. Gasol, *Ocean warming enhances respiration and carbon demand of coastal microbial plankton. *Global Change Biology* 13, 1–8 \(2007\)*](#)

The increase of anthropogenic CO₂ during this century is expected to cause warming of large regions of the ocean. Microbes lead the biological role in the CO₂ balance of marine ecosystems, their activity is known to be influenced by temperature, and it is important to constrain and quantify these effects on bacterial carbon use. Furthermore, if warming were to enhance the carbon demand (production + respiration) of planktonic microbes but would maintain their efficiency low (as it generally is), then most carbon consumed would end up respired. We designed a strategy in which we measured bacterial production and respiration throughout a seasonal cycle in a coastal Mediterranean site, and determined experimentally the effects of ca. 2.5 °C on these processes. We show that warming will increase nearly 20 % the total carbon demand of coastal microbial plankton without any effect on their (commonly low) growth efficiency, which could generate a positive feedback between coastal warming and CO₂ production.

[Vallina, S. M., and R. Simó, *Strong relationship between DMS and the solar radiation dose over the global surface ocean. *Science* 315: 506-509 \(2007\).*](#)

Marine biogenic dimethylsulfide (DMS) is the main natural source of tropospheric sulfur, which may play a key role in cloud formation and albedo over the remote ocean. Through a global data analysis, we showed that DMS concentrations are highly positively correlated with the solar radiation dose in the upper mixed layer of the open ocean, irrespective of latitude, plankton biomass or temperature. This is a necessary condition for the feasibility of a negative feedback in which light-attenuating DMS emissions are in turn driven by the light dose received by the pelagic ecosystem.

[Vallina, S.M., R. Simó, S. Gassó, C. de Boyer-Montégut, E. del Río, E. Jurado, and J. Dachs. *Analysis of a potential “solar radiation dose–dimethylsulfide–cloud condensation nuclei” link from globally mapped seasonal correlations, *Global Biogeochemical Cycles* 21, GB2004, doi:10.1029/2006GB002787 \(2007\).*](#)

The CLAW postulate states that an increase in solar irradiance or in the heat flux to the ocean can trigger a biogeochemical response to counteract the associated increase in temperature and available sunlight. This natural (negative) feedback mechanism would be based on a multistep response: first, an increase in seawater dimethylsulfide concentrations (DMS_w) and therefore its fluxes to the atmosphere (DMS_{flux}); second, an increase in the atmospheric cloud condensation nuclei (CCN) burden as a consequence of DMS oxidation to form biogenic CCN (CCN_{bio}); and third, an increase in cloud albedo due to higher CCN numbers. Monthly global climatological fields of the solar radiation dose in the upper mixed layer

(SRD), surface oceanic DMS_{sw}, model outputs of hydroxyl radical concentrations (OH), and satellite-derived CCN numbers (CCNs) are analyzed in order to evaluate the proposed “solar radiation dose-DMS-CCN” link from a global point of view. OH is included as the main atmospheric oxidant of the estimated DMS_{sw} flux to produce CCN_{bio}. Global maps of seasonal correlations between the variables show that the solar radiation dose is highly (positively) correlated with seawater dimethylsulfide over most of the global ocean and that atmospheric DMS oxidation is highly (positively) correlated with CCNs over large regions. These couplings are stronger at high latitudes, whereas the regions with negative or no correlation are located at low latitudes around the equator. However, CCN_{bio} estimates for 15 regions of the global ocean show that DMS oxidation can be an important contributor to the CCNs burden only over pollution-free regions, while it would have a minor contribution over regions with high loads of continental aerosols. Globally, the mean annual contribution of CCN_{bio} to total CCNs is estimated to be ~30%. Our results support that an oceanic biogenic mechanism that modulates cloud formation and albedo can indeed occur, although its impact seems rather weak over regions under a strong influence of continental aerosols. Nevertheless, our approach does not fully rule out that the observed correlations are due to an independent seasonal variation of the studied variables; seasonal couplings are necessary but not sufficient conditions to prove the CLAW hypothesis.

[Vallina, S. M., R. Simó, and M. Manizza, Weak response of oceanic dimethylsulfide to upper mixing shoaling induced by global warming. *Proceeding of the National Academy of Sciences*, en premsa \(2007\).](#)

The solar 1 radiation dose in the oceanic upper mixed layer (SRD) has recently been identified as the main climatic force driving global dimethylsulfide (DMS) dynamics and seasonality. Since DMS is suggested to exert a cooling effect on the Earth radiative budget through its involvement in the formation and optical properties of tropospheric clouds over the ocean, a positive relationship between DMS and the SRD supports the occurrence of a negative feedback between the oceanic biosphere and climate, as postulated 20 years ago. Such a natural feedback might partly counteract anthropogenic global warming through a shoaling of the mixed layer depth (MLD) and a consequent increase of the SRD and DMS concentrations and emission. By applying two globally-derived DMS diagnostic models to global MLD and chlorophyll simulated with an Ocean General Circulation Model for a 50% increase of atmospheric CO₂ and an unperturbed control run, we have estimated the response of the DMS-producing pelagic ocean to global warming. Our results show a net global increase in surface DMS concentrations, especially in summer. This increase, however, is so weak (globally 1.2%) that it can hardly be relevant as compared with the radiative forcing of the increase of greenhouse gases. This contrasts with the seasonal variability of DMS (1000-2000% summer-to-winter ratio). We suggest that the 'plankton - DMS - clouds - Earth albedo feedback' hypothesis is less strong a long-term thermostatic system than a seasonal mechanism that contributes to regulate the solar radiation doses reaching the Earth's biosphere.

[Vila-Costa, M., R. P. Kiene, and R. Simó, Seasonal variability of the dynamics of dimethylated sulfur compounds in a coastal northwest Mediterranean site, *Limnology Oceanography*, en premsa \(2007\).](#)

We studied the seasonal variation of biotic and abiotic processes and their physico-chemical forcing factors involved in the production and consumption of dimethylsulfide (DMS) and its precursor dimethylsulfoniopropionate (DMSP) at a coastal sampling station in the northwestern Mediterranean. Monthly samplings of surface seawater over an 18-month period revealed that algal-associated DMSP and dimethylsulfoxide (DMSO) did not follow total phytoplankton biomass (measured as chlorophyll a (Chl a)). DMSP concentrations peaked one or two months later than the late winter Chl a bloom, following phytoplankton succession, while particulate DMSO was maximal in summer. Both Chl a-normalized concentrations (DMSP:Chl a and DMSO:Chl a) exhibited a clear seasonality with maxima in summer, which was indicative of concurrent phytoplankton succession and physiological acclimation towards higher dimethylated sulfur producing taxa in summer. DMS concentrations also showed clear maxima in mid summer and minima in winter, which is anti-correlated with Chl a. Gross DMS production rates were higher in summer, coinciding with higher DMSP-to-DMS conversion yields, and exceeded microbial DMS consumption in this season. Heterotrophic bacteria and DMSP-assimilating phytoplankton only accounted for a portion (annual average 52%) of total DMSP transformations, suggesting that phytoplankton DMSP-lyases, either in stressed cells or upon grazing by herbivores, must play a more important role as DMS sources than is generally believed. Calculated photolysis and measured microbial consumption alternated in dominance as DMS sinks over the year, with ventilation generally being a minor loss process. Under higher solar radiation (from March to September), photolysis followed variations of colored dissolved organic matter (cDOM), a known DMS photosensitizer.

A-8. Paleoceanografia i Paleoclimatologia:

Wang, L., M. Sarnthein, H. Erlenkeuser, J. O. Grimalt, P. Grootes, S. Heilig, E. Ivanova, M. Kienast, C. Pelejero, and U. Pflaumann, East Asian monsoon climate during the late Pleistocene: High-resolution sediment records from the South China Sea, *Marine Geology*, 156, 243-282 (1999).

Based on the study of 10 sediment cores and 40 core-top samples from the South China Sea (SCS) we obtained proxy records of past changes in East Asian monsoon climate on millennial to bidecadal time scales over the last 220,000 years. Climate proxies such as global sea level, estimates of paleotemperature, salinity, and nutrients in surface water, ventilation of deep water, paleowind strength, freshwater lids, fluvial and/or eolian sediment supply, and sediment winnowing on the sea floor were derived from planktonic and benthic stable-isotope records, the distribution of siliciclastic grain sizes, planktonic foraminifera species, and the UK37 biomarker index. Four cores were AMS-14C-dated. Two different regimes of monsoon circulation dominated the SCS over the last two glacial cycles, being linked to the minima and maxima of Northern Hemisphere solar insolation. (1) Glacial stages led to a stable estuarine circulation and a strong O₂-minimum layer via a closure of the Borneo sea strait. Strong northeast monsoon and cool surface water occurred during winter, in part fed by an inflow from the north tip of Luzon. In contrast, summer temperatures were as high as during interglacials, hence the seasonality was strong. Low wetness in subtropical South China was opposed to large river input from the emerged Sunda shelf, serving as glacial refuge for tropical forest. (2) Interglacials were marked by a strong inflow of warm water via the Borneo sea strait, intense upwelling southeast of Vietnam and continental wetness in China during summer, weaker northeast monsoon and high sea-surface temperatures during winter, i.e. low seasonality. On top of the long-term variations we found millennial- to centennial-scale cold and dry, warm and humid spells during the Holocene, glacial Terminations I and II, and Stage 3. The spells were coeval with published variations in the Indian monsoon and probably, with the cold Heinrich and warm Dansgaard-Oeschger events recorded in Greenland ice cores, thus suggesting global climatic teleconnections. Holocene oscillations in the runoff from South China centered around periodicities of 775 years, ascribed to subharmonics of the 1500-year cycle in oceanic thermohaline circulation. 102/84-year cycles are tentatively assigned to the Gleissberg period of solar activity. Phase relationships among various monsoon proxies near the onset of Termination IA suggest that summer-monsoon rains and fluvial runoff from South China had already intensified right after the last glacial maximum (LGM) insolation minimum, coeval with the start of Antarctic ice melt, prior to the $\delta^{18}\text{O}$ signals of global sea-level rise. Vice versa, the strength of winter-monsoon winds decreased in short centennial steps only 3000-4000 years later, along with the melt of glacial ice sheets in the Northern Hemisphere.

Cacho, I., C. Pelejero, J. O. Grimalt, A. Calafat, and M. Canals, C₃₇ alkenone measurements of sea surface temperature in the Gulf of Lions (NW Mediterranean), *Organic Geochemistry*, 30, 557-566 (1999).

A study of the C₃₇ alkenone compositions in suspended particulate matter in the northwestern Mediterranean Sea has shown a correspondence between UK'37 and sea surface temperature that significantly deviates from the general equation regularly observed in most marine world areas (Müller et al., 1998). However, the temperatures measured in the core top sediments using the general equation are in agreement with the annual average water column temperatures between 0-40 m depth. These discrepancies suggest that despite the rather constant correlation between UK'37 and seawater temperature throughout the world oceans, specific calibrations should be developed for each new area of application of the C₃₇ alkenones for paleotemperature determination.

Wang, L., M. Sarnthein, H. Erlenkeuser, P. M. Grootes, J. O. Grimalt, C. Pelejero, and G. Linck, Holocene variations in Asian monsoon moisture: A bidecadal sediment record from the South China Sea, *Geophysical Research Letters*, 26, 2889-2892 (1999).

The East Asian monsoon system involves extensive transport of sensible/latent heat between land and sea and from low to high latitudes. Our high resolution, bidecadal marine records present a first detailed history of monsoon climate change over the Holocene. The high-amplitude perturbation in monsoon moisture centered at 8,150 years ago and the monsoon maximum in the Early Holocene show inter-hemispheric teleconnections to both a cool episode in Greenland and to the Indian monsoon monitored in the Arabian Sea. Periodicities of 84, 102 and, especially, near 775 years in monsoon variation suggest a climatic forcing both by long-term oscillations in thermohaline circulation and (possibly) solar activity cycles.

Cacho, I., J. O. Grimalt, C. Pelejero, M. Canals, F. J. Sierro, J. A. Flores, and N. J. Shackleton, Dansgaard-Oeschger and Heinrich event imprints in Alboran Sea paleotemperatures, *Paleoceanography*, 14, 698-705 (1999).

Past sea surface temperature (SST) evolution in the Alboran Sea (western Mediterranean) during the last 50,000 years has been inferred from the study of C₃₇ alkenones in International Marine Global Change Studies MD952043 core. This record has a time resolution of about 200 years allowing the study of millennial-scale and even shorter climatic changes. The

observed SST curve displays characteristic sequences of extremely rapid warming and cooling events along the glacial period. Comparison of this Alboran record with $\delta^{18}\text{O}$ from Greenland ice (Greenland Ice Sheet Project 2 core) shows a strong parallelism between these SST oscillations and the Dansgaard-Oeschger events. Five prominent cooling episodes standing out in the SST profile are accompanied by an anomalous high abundance of *Neogloboquadrina pachyderma* sinistral which is confined to the duration of these cold intervals. These features and the isotopic record reflect drastic changes in the surface hydrography of the Alboran Sea in association with Heinrich events H1-5.

[Pelejero, C., J. O. Grimalt, M. Sarnthein, L. Wang, and J. A. Flores, Molecular biomarker record of sea surface temperature and climatic change in the South China Sea during the last 140,000 years, *Marine Geology*, 156, 109-121 \(1999\).](#)

The $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ isotopic composition of *Globigerinoides ruber*, the concentration of C37 alkenones, n-nonacosane and n-hexacosan-1-ol and the populations of coccolith species in core 17961-2 have been used to characterize the climatic changes which occurred in the South China Sea (SCS) during the last climatic cycle. The relative composition of di- and triunsaturated C37 alkenones, the UK37 index, has been used to estimate the variation in sea surface temperatures. The concentrations of the terrigenous markers n-nonacosane and n-hexacosan-1-ol have allowed to infer changes in continental water dynamics during the glacial and interglacial times. The stratigraphic record of these compounds has shown that the influence of continental waters (i.e., the Molengraaff River) and restricted water circulation in SCS gave rise to a marginal system of higher but slower response to climatic change. Both in terminations I and II, the change from glacial to interglacial conditions involves a considerable reduction of continental water input into this semi-enclosed system. The high resolution study of the biomarker proxies in Termination I has shown that the SST increase lagged about 2.3 ky the ^{18}O isotopic decrease of *Cibicidoides wuellerstorfi*. Probably, the SST increase corresponds to the period of the Sunda Shelf inundation onset.

[Pelejero, C., J. O. Grimalt, S. Heilig, M. Kienast, and L. Wang, High resolution \$\text{U}^{\text{K}}_{37}\$ -temperature reconstructions in the South China Sea over the last 220 kyrs, *Paleoceanography*, 14, 224-231 \(1999\).](#)

Past sea surface temperatures (SST) in the northern and southern areas of the South China Sea have been reconstructed for the past 220 kyr using the UK³⁷ alkenone index. The SST profiles follow the glacial/interglacial pattern exhibiting differences between Last Glacial Maximum and Holocene that are 1-3°C larger than those observed at the same latitudes in the Atlantic and Pacific Oceans. In Termination I both planktonic foraminiferal and SST exhibit well-defined Bølling-Allerød and Younger Dryas events with temperature differences between both periods of 0.8 and 0.4°C in north and south, respectively. SSTs record a constant north-south difference of 1°C in the interglacials and nearly 2.5°C in the glacial stages. These differences define two distinct climatic and water circulation patterns that correspond with glacial/interglacial sea level oscillations which opened and closed water exchange with the tropical Indo-Pacific Ocean through the present Sunda Shelf.

[Pelejero, C., M. Kienast, L. Wang, and J. O. Grimalt, The flooding of Sundaland during the last deglaciation: Imprints in hemipelagic sediments from the southern South China Sea, *Earth and Planetary Science Letters* 171, 661-671 \(1999\).](#)

During the last 30 ka, the South China Sea (SCS) experienced pronounced palaeogeographic changes associated with the postglacial sea level rise, which significantly modified the hydrography of this marginal sea. The most crucial effects in the southern part of the basin were the submergence of Sundaland and the opening of the southern channels connecting the SCS to the tropical Indo-Pacific. Isotopic, sedimentological and organic geochemical parameters determined in two sediment cores from the southern SCS, one in the open sea and the other close to the continental shelf (sites 17961 and 17964, respectively) show that the main hydrographical changes during this period were related to critical thresholds in sea level rise. The main changes occurred at about 15-13.5 ky BP, coincident with Meltwater Pulse (MWP) Ia, when sea surface temperatures (SSTs) at both sites experienced a rapid 1.5°C rise, and the clay content and n-nonacosane concentrations dropped significantly. Both trends reflect a rapid retreat of the coastline and an initial flooding of Sundaland at that time. A second important change, starting with the beginning of MWP Ib at about 11.5 ky BP and culminating at 10 ky BP, involved the establishment of modern hydrographic conditions. This is evident from the rapid convergence of the foraminiferal oxygen isotope records and the establishment of Holocene SST values. These results highlight the need to include the flooding/emergence of Sundaland as an important boundary condition in future modelling studies of Asian palaeomonsoons.

[Rosell-Melé, A., E. Bard, K.-C. Emeis, J. O. Grimalt, P. Müller, R. Schneider, I. Bouloubassi, B. Epstein, K. Fahl, A. Fluegge, K. Freeman, M. Goñi, U. Güntner, D. Hartz, S. Hellebust, T. Herbert, M.](#)

Ikehara, R. Ishiwatari, K. Kawamura, F. Kenig, J. de Leeuw, S. Lehman, L. Mejanelle, N. Ohkouchi, R. D. Pancost, [C. Pelejero](#), F. Prahl, J. Quinn, J.-F. Rontani, F. Rostek, J. Rullkotter, J. Sachs, T. Blanz, K. Sawada, D. Schulz-Bull, E. Sikes, C. Sonzogni, Y. Ternois, G. Versteegh, J. Volkman, and S. Wakeham, Precision of the current methods to measure the alkenone proxy $U^{K'}_{37}$ and absolute alkenone abundance in sediments: results of an inter-laboratory comparison study, *Geochemistry Geophysics Geosystems* 2, doi:10.1029/2000GC000141 (2001).

Measurements of the $U^{K'}_{37}$ index and the absolute abundance of alkenones in marine sediments are increasingly used in paleoceanographic research as proxies of past sea surface temperature and haptophyte (mainly coccolith-bearing species) primary productivity, respectively. An important aspect of these studies is to be able to compare reliably data obtained by different laboratories from a wide variety of locations. Hence the intercomparability of data produced by the research community is essential. Here we report results from an anonymous interlaboratory comparison study involving 24 of the leading laboratories that carry out alkenone measurements worldwide. The majority of laboratories produce data that are intercomparable within the considered confidence limits. For the measurement of alkenone concentrations, however, there are systematic biases between laboratories, which might be related to the techniques employed to quantify the components. The maximum difference between any two laboratories for any two single measurements of $U^{K'}_{37}$ in sediments is estimated, with a probability of 95% to be $<2.1^{\circ}\text{C}$. In addition, the overall within-laboratory precision for the $U^{K'}_{37}$ temperature estimates is estimated to be $<1.6^{\circ}\text{C}$ (95% probability). Similarly, from the analyses of alkenone concentrations the interlaboratory reproducibility is estimated at 32%, and the repeatability is estimated at 24%. The former is compared to a theoretical estimate of reproducibility and found to be excessively high. Hence there is certainly scope and a demonstrable need to improve reproducibility and repeatability of $U^{K'}_{37}$ and especially alkenone quantification data across the community of scientists involved in alkenone research.

[Grimalt, J.O., E. Calvo, and C. Pelejero](#), Sea surface paleotemperature errors in $U^{K'}_{37}$ estimation due to alkenone measurements near the limit of detection, *Paleoceanography*, 16, 226-232 (2001).

Major errors ($> 0.5^{\circ}\text{C}$) are produced in paleotemperature estimation with the C37 alkenone method when the amount of the diunsaturated or triunsaturated species, C37:2 and C37:3, respectively, approaches the limit of detection. These errors are more commonly encountered with C-37:3 because of its higher adsorption to gas chromatographic (GC) columns. They are particularly relevant at low sedimentary C37 alkenone concentrations and may easily increase to temperature differences of $2^{\circ} - 4^{\circ}\text{C}$ depending on the $U^{K'}_{37}$ values and the ratio between the C37:3 signal and limit of detection. Mathematical expressions for the description of the analytical constraints derived from this detection limit problem are given. A quality assurance guideline based on sample dilution (three times) and calculation of the sea surface temperature error is proposed for assessment of reliable measurements. Reevaluation of literature data in the light of the equations reported in the present study suggest that some previously reported alkenone geochemical effects, such as variation in $U^{K'}_{37}$ temperatures due to postdepositional oxidation, may reflect deviations in the GC measurements due to changes in C37 alkenone concentration.

[Kienast, M., S. E. Calvert, C. Pelejero, and J. O. Grimalt](#), A critical review of marine sedimentary $\delta^{13}\text{C}$ -pCO₂ estimates: New palaeorecords from the South China Sea and a revisit of other low-latitude $\delta^{13}\text{C}$ -pCO₂ records, *Global Biogeochemical Cycles*, 15, 113-127 (2001).

In an attempt to understand better the local biogeochemistry of the South China Sea (SCS) and to unravel the contribution of this marginal low-latitude basin to changes in atmospheric CO₂ concentrations, we analyzed the carbon isotopic composition of organic matter ($\delta^{13}\text{C}_{\text{org}}$) in four sediment cores from throughout the SCS covering the last 220 kyr. Higher values (around -19.5 to -20.5‰) mark glacial stages, while lower values (around -21 to -22.5‰) are characteristic of interglacials. Following well established procedures, the $\delta^{13}\text{C}_{\text{org}}$ records are converted to local pCO₂ estimates. On the basis of these and other low-latitude $\delta^{13}\text{C}_{\text{org}}$ -pCO₂ estimates from the literature, we present a critical evaluation of the use of $\delta^{13}\text{C}$ of bulk sedimentary organic matter to hindcast past changes in local CO₂(aq). Three crucial pitfalls are identified. (1) Given the present inability to quantify precisely the time-varying amount of terrigenous Corg input to marine sediments, absolute values of pCO₂ estimates based on bulk sedimentary C-org are questionable. (2) None of the low-latitude sedimentary $\delta^{13}\text{C}_{\text{org}}$ -pCO₂ records shows the expected correlation between temporal changes in upwelling intensity and CO₂ estimates, most likely due to the antagonistic influences of CO₂(aq) and phytoplankton growth rate on $\delta^{13}\text{C}_{\text{org}}$. (3) A detailed comparison of marine $\delta^{13}\text{C}_{\text{org}}$ -pCO₂ records with the Vostok CO₂ record reveals significant differences in phasing, specifically at the end of the last deglaciation and during the oxygen isotope stage 5/4 transition. However, in areas where equilibrium between oceanic and atmospheric CO₂ occurs, for example the SCS and the Mediterranean, the timing of changes in $\delta^{13}\text{C}_{\text{org}}$ should agree with the CO₂ record from ice cores if $\delta^{13}\text{C}_{\text{org}}$ is a reliable proxy for changes in CO₂(aq). Taken together, the compilation of records presented here cautions the use of $\delta^{13}\text{C}_{\text{org}}$ as an unambiguous tracer of dissolved molecular CO₂ in the surface ocean and calls for a re-evaluation of the role of the low-

latitude ocean on temporal changes in atmospheric CO₂.

[Calvo, E., C. Pelejero, J. C. Herguera, A. Palanques, and J. O. Grimalt, Insolation dependence of the Southeastern Subtropical Pacific sea surface temperature over the last 400 kyrs, *Geophysical Research Letters*, 28, 2481-2484 \(2001\).](#)

The present study describes the first sea surface temperature (SST) reconstruction in the southeastern Subtropical Pacific Ocean, offshore the South American coast. The obtained record encompasses the last 400 kyr and follows the characteristic glacial/interglacial pattern defined by global ice volume. However, SST leads the $\delta^{18}\text{O}$ isotopic record reflecting the role of the low latitudes areas in driving climate change. SST in the Holocene is lower by about 0.5-0.8 °C than maximal SST in stages 5e, 7, 9 and 11. SST in stages 2-4 is lower by about 0.6-1.3 °C than minimal SST in stages 6, 8 and 10. These features are similar to SST records obtained in the South Atlantic Ocean pointing to a general inter-basinal behaviour at these low latitudes. For most of the record, the observed long-term SST evolution is well correlated with the orbital parameter of eccentricity, which modulates the insolation at low latitudes. However, at low eccentricity values (Stages 11-9 and Termination I), SST is driven by obliquity, exhibiting a dependence from high latitude climatic responses.

[Villanueva J., E. Calvo, C Pelejero, J. O. Grimalt, A. Boelaert, and L. Labeyrie, A latitudinal productivity band in the Central North Atlantic over the last 270 kyrs: An alkenone perspective, *Paleoceanography*, 16, 617-626 \(2001\).](#)

Productivity changes in the central North Atlantic Ocean have been traced by means of the total C₃₇ alkenone contents along two sediment cores located at 43°N and 37°N. Both alkenone signals revealed the occurrence of discrete productivity events every 23 kyr. Spectral analyses highlight the presence of a dominant 23-kyr periodicity in the alkenone signal, which is highly coherent to the precession index. However, a close comparison revealed small but relevant differences in the timing of several of the productivity events recorded at both locations. These asynchronies suggest that the alkenone maxima do not necessarily reflect a general increase of productivity over the North Atlantic. We propose that the events are related to a latitudinal band of productivity that moves northward and southward over time. Satellite-derived productivity estimates show that the present location of this band is 45°–55°N. To illustrate this hypothesis we have constructed a conceptual model that reconstructs the temporal changes of productivity at one given location by assuming a productivity band that evolves latitudinally over time. The model is able to reconstruct the main features of the alkenone records, namely, (1) the occurrence of discrete and abrupt productivity events, (2) the asynchrony at different latitudes, and (3) the bimodal pattern of many of the productivity peaks.

[Calvo, E., J. Villanueva, J. O. Grimalt, A. Boelaert, and L. Labeyrie, New insights into the glacial latitudinal temperature gradients in the North Atlantic. Results from U^{K'}₃₇ - sea surface temperatures and terrigenous inputs, *Earth and Planetary Science Letters*, 188, 509-519 \(2001\).](#)

Sea surface temperatures (SST) and input of continental materials have been reconstructed from the study of the long-chain alkenones and n-alkanes, respectively, in a core located in the western side of the Mid-Atlantic Ridge (MD952037, 37°05'N 32°02'W, 2630 m depth). Both the long- and short-term variability recorded by the temperatures and the planktonic $\delta^{18}\text{O}$ are basically the same over the last 280 kyr, showing a clear glacial/interglacial evolution. Comparison with core SU90/08, located only 6° north and directly influenced by the cold polar waters associated with the polar front during glacial times, revealed different climatic conditions during glacial periods at both locations. Whereas core MD952037 recorded similar SST values during the last two glacial periods (ca. 14–15°C), the northern core displayed colder conditions during isotopic stage 2 (8–10°C) than in stage 6 (13–15°C). These results indicate the existence of a well-developed steep north-south gradient between 37 and 43°N during the last glacial period but not during stage 6, which suggests a southern expansion of the polar front during the last glacial maximum.

[Marchal, O., I. Cacho, T. F. Stocker, J. O. Grimalt, E. Calvo, B. Martrat, N. J. Shackleton, M. Vautravers, E. Cortijo, S. van Kreveld, C. Andersson, N. Koç, M. R. Chapman, L. Saffi, J. C. Duplessy, M. Sarnthein, J. L. Turon, J. Duprat, and E. Jansen, Apparent long-term cooling of the sea surface in the northeast Atlantic and Mediterranean during the Holocene, *Quaternary Science Reviews*, 21, 455-483 \(2002\).](#)

Reconstructions of upper ocean temperature (T) during the Holocene (10⁰ ka B.P.) were established using the alkenone method from seven, high accumulation sediment cores raised from the northeast Atlantic and the Mediterranean Sea (36°N–75°N). All these paleo-T records document an apparent long-term cooling during the last 10 kyr. In records with indication of a constant trend, the apparent cooling ranges from -0.27 to -0.15°C kyr⁻¹. Records with indication of time-

variable trend show peak-to-peak amplitudes in apparent temperatures of $1.2\text{--}2.9^{\circ}\text{C}$. A principal component analysis shows that there is one factor which accounts for a very large fraction (67%) of the total variance in the biomarker paleo-T records and which dominates these records over other potential secondary influences. Two possible contributions are (1) a widespread surface cooling, which may be associated with the transition from the Hypsithermal interval ($\sim 9\text{--}5.7$ ka B.P.) to the Neoglaciation ($\sim 5.7\text{--}0$ ka B.P.); and (2) a change in the seasonal timing and/or duration of the growth period of alkenone producers (prymnesiophyte algae). The first contribution is consistent with many climate proxy records from the northeast Atlantic area and with climate model simulations including Milankovitch forcing. The second contribution is consistent with the divergence between biomarker and summer faunal paleo-T from early to late Holocene observed in two cores. Further work is necessary, and in particular the apparent discordance between biomarker and faunal T records for the relative stable period must be understood, to better constrain the climatic and ecological contributions to the apparent cooling observed in the former records.

[Calvo, E., J. O. Grimalt, and E. Jansen, High resolution \$U^{K}_{37}\$ sea surface temperature reconstruction in the Norwegian Sea during the Holocene. *Quaternary Science Reviews*, 21, 1385-1394 \(2002\).](#)

A study of the C37 alkenone distributions in core MD952011 from the Norwegian Sea (about 65°N) has allowed to evaluate the applicability of the UK37 and UK'37 indexes in these cold waters. The use of the first defined UK37 appears to be the most appropriate to estimate sea surface temperatures (SST) allowing a high resolution SST reconstruction for the Holocene section. At this site, the warmest SST values were recorded during the first half of the Holocene, between 8.5 and 5.5 ka BP, after a gradual warming. Since then, the SST evolution of the late Holocene exhibits a cooling trend towards present values, in concordance with the decreasing summer insolation at these high latitudes. In terms of variability, higher SST changes were observed in the warmer than in the cooler periods, $\pm 2^{\circ}\text{C}$ and $\pm 0.5^{\circ}\text{C}$, respectively.

[Diz, P., G. Francés, C. Pelejero, J. O. Grimalt, and F. Vilas, The last 3000 years in the Ría de Vigo \(NW Iberian Margin\): climatic and hydrographic signals, *The Holocene*, 12, 383-392 \(2002\).](#)

The hydrographic evolution of the Ría de Vigo (NW Spain) during the last 3000 years has been reconstructed using benthic foraminiferal assemblages, stable oxygen isotopes, molecular biomarkers and sea-surface temperatures (SST) reconstructed from the U-37(K') index. Benthic oxygen isotopes and SST records provide evidence of episodic salinity contrasts between surface and bottom waters. The comparison of SSTs with other climate records for the Northern Hemisphere has allowed the inference of oceanographic and climatic signals, which describe the changes in hydrographic conditions of the ria. In general, two different periods can be recognized. From 975 cal. BC to cal. AD 1000, the organic carbon is mainly of continental origin, benthic foraminiferal assemblages are typical of environments that are poorly oxygenated, rich in organic matter and dominated by euhaline taxa. Percentages of planktonic foraminifera are low and SSTs are warmer than today. These data suggest a restricted environment where the exchange with open ocean waters was diminished. At cal. AD 1000, an important hydrographic change in the ria circulation involved an intensification of coastal upwelling processes as reflected in colder SSTs and increases in the contribution of marine organic carbon and planktonic and opportunistic benthic foraminifera. In these conditions, the sediments of the ria recorded not only local factors but also several well-known Northern Hemisphere climate signals.

[Kienast, M., T. J. J. Hanebuth, C. Pelejero, and S. Steinke, Synchronicity of meltwater pulse 1a and the Bolling warming: New evidence from the South China Sea, *Geology*, 31, 67-70 \(2003\). *This paper was selected for comments at Editor's Choice, Science*, 299, 24 Jan \(2003\).](#)

A twofold decrease in long-chain n-alkane (n-nonacosane) concentrations in a downcore record from the northern South China Sea indicates a rapid drop in the supply of terrigenous organic matter to the open South China Sea during the last deglaciation, paralleled by an equally rapid increase in sea-surface temperatures, corresponding with the Bolling warming at 14.7 ka. The sudden drop in terrigenous organic matter delivery to this marginal basin is interpreted to reflect a short-term response of local rivers to rapid sea-level rise, strongly implying that the Bolling warming and the onset of meltwater pulse (MWP) 1a are synchronous. This phase relation contrasts with the widely cited onset of this MWP 1a ca. 14 ka, and implies that previous studies postulating a weakening of deep-water formation in the North Atlantic due to massive meltwater discharge during MWP 1a need to be reevaluated.

[Calvo, E., C. Pelejero, and G. Logan, Pressurized liquid extraction of selected molecular biomarkers in deep sea sediments used as proxies in paleoceanography, *Journal of Chromatography A*, 989, 197-205 \(2003\).](#)

Pressurized liquid extraction (PLE) has been performed on a suite of deep-sea sediments to assess its capability as an extraction technique in the analysis of molecular biomarkers used in paleoceanography. Specific compounds assessed

comprise long chain alkenones, n-alkanes, n-alcohols and, additionally, one diol and one keto-ol. These have been extracted by both PLE and ultrasonication for comparison. One key result is that the UK37 index (based on the degree of unsaturation of the alkenones and used as a paleothermometer in paleoceanography) remains intact after both extraction techniques. In terms of biomarker concentrations, which are often used to qualitatively assess changes in marine productivity and/or terrigenous inputs, PLE is substantially more efficient than ultrasonication, providing higher amounts of extracted constituents, particularly for polar compounds.

[Pelejero, C., and E. Calvo, The upper end of the U^K₃₇ temperature calibration revisited, *Geochemistry, Geophysics, Geosystems*, 4, 1014, doi:10.1029/2002GC000431 \(2003\).](#)

Being able to decipher paleo sea surface temperatures for warm oceanic waters is of the utmost importance to further evaluate the role of the tropics in global climate change. The UK37 index is one of such paleothermometers, although the warm range of temperatures often poses serious analytical challenges. This paper discusses and reviews several important aspects of the UK37 index calibration for waters warmer than 26°–27°C. Amongst them, insights into the possible existence of a limit above which the UK37 index is not able to accurately record temperature variations are presented. Some warnings are also given on the misleading practice and expected consequences of reporting UK37 index values of unity in the cases when abundances of the minor triunsaturated alkenone below detection limit are encountered. Future directions toward an improved knowledge of the behaviour of the UK37 calibration for warm waters are suggested.

[Pelejero, C., Terrigenous n-alkane input in the South China Sea: high-resolution records and surface sediments, *Chemical Geology*, 200, 89-103 \(2003\).](#)

Molecular abundances of n-nonacosane are reported for a suite of 44 surface sediments and four deep sea cores distributed throughout the South China Sea (SCS), covering the last 220 ky at different time resolutions. The patterns of glacial to interglacial variability of the concentrations of this terrigenous marker are parallel for all cores, taking values linearly inversely correlated to the UK³⁷ index sea surface temperatures (SST), with high concentrations during cold-glacial intervals and low concentrations during warm-interglacial periods. The oscillations of this terrigenous marker likely result from the emergence and flooding of the shelves caused by sea-level variations which, together with SCS SSTs, have a clear dependency on the Northern Hemisphere climate evolution. Calculation of accumulation rates for the northernmost core together with the modern distribution of n-nonacosane concentrations in surface sediments evidences the complexity of sedimentation patterns in the northern SCS. In particular, and in agreement with recent studies, terrigenous materials deposited there might originate from areas different than the highly loaded Pearl River. For paleoceanographic purposes, the noticeable general pattern of the n-alkane concentration down-core profiles for the four cores studied, a parameter apparently unaffected by changes in sedimentation rates, prompts its use as a tracer of variations in terrigenous input into this basin over glacial to interglacial times.

[Pelejero, C., E. Calvo, G. A. Logan, and P. De Deckker, Marine Isotopic Stage 5e in the Southwest Pacific: Similarities with Antarctica and ENSO inferences. *Geophysical Research Letters*, 30, 2185, doi:10.1029/2003GL018191 \(2003\).](#)

A detailed record of alkenone-derived sea-surface temperatures (SSTs) offshore western New Zealand has been generated for the penultimate deglaciation and last interglacial. SSTs were 3.5 to 4.5 °C warmer than present, peaking 4.5 thousand years ahead of ice volume minima. The short duration of Marine Isotopic Stage 5e off New Zealand exhibits a striking parallelism to the record of air temperatures at Vostok, Antarctica. Changes in latitudinal SST gradients for the Southwest Pacific from New Zealand to the equator are also assessed, showing values consistently lower than today. In this region, this situation usually occurs during periods with positive values of the Southern Oscillation Index and thus La Niña conditions. By inference, we suggest that our assessed low thermal gradients might be indicative of a prevalence of either persistent or more frequent La Niña like conditions, particularly during early Stage 5e.

[Calvo, E., C. Pelejero, G. Logan, and P. De Deckker, Dust-induced changes in phytoplankton composition in the Tasman Sea during the last four glacial cycles, *Paleoceanography*, 19, PA2020, doi:10.1029/2003PA000992 \(2004\).](#)

An increase in iron supply associated with enhanced dust inputs could be responsible for higher marine phytoplankton production leading to the typically lower glacial atmospheric CO₂ concentrations, as suggested by the “iron hypothesis.” The enhanced dust supply may also have provided the oceans with significant amounts of silica, which would have favored the growth of diatoms over coccolithophores, as suggested by the “silica hypothesis.” Here we present new data on molecular biomarkers in a sediment core from the midlatitudes of the Southern Hemisphere, which reveal dust-induced changes in the relative contribution of the phytoplankton to total productivity. Our results illustrate a shift in the relative

abundance of siliceous over calcareous organisms during glacial times, when terrestrial aeolian input was enhanced. Although we did not detect a significant glacial decrease in coccolithophorid productivity, the decrease in the CaCO₃/Corg rain ratio could have still contributed to some extent in lowering atmospheric CO₂ levels.

[Álvarez, M. C., J. A. Flores, F. J. Sierro, P. Diz, G. Francés, C. Pelejero, and J. O. Grimalt, Millennial surface water dynamics in the Ría de Vigo during the last 3000 years as revealed by coccoliths and molecular biomarkers, *Palaeogeography, Palaeoclimatology, Palaeoecology* 218, 1–13 \(2005\).](#)

A combined study of coccolith assemblages and biomarkers in a gravity core collected from the Ría de Vigo (NW Spain) allowed us to reconstruct the paleoenvironmental conditions for the last 3000 years. The quantitative distribution of coccolithophore species points to three different intervals within the core, dated by AMS radiocarbon measurements. The first interval (ca. 975 BC-252 AD), characterized by high abundances of *Calcidiscus leptoporus* and *Gephyrocapsa muelleriae*, is thought to represent moderate water temperatures, suggesting a transition from a warmer to a cooler period. The second interval (ca. 252-1368 AD), characterized by the dominance of *Coccolithus pelagicus*, *Helicosphaera carteri* and *Syracosphaera* spp., and a high concentration of hexacosanol linked to terrestrial input, is interpreted as having been a humid period with fluvial input. The third interval (ca. 1368 AD-1950) is characterized by a high abundance of *Gephyrocapsa oceanica*, high alkenone values and low values of hexacosanol, and is thought to represent a period dominated by oceanic conditions within the Ría. Taking into account the ocean-atmospheric system affecting the region studied, here we propose an alternation in the mean state of North Atlantic Oscillation (NAO) at millennial time scales. A well-developed upwelling system and an active Ría-ocean connection during the warmer interval I suggest a NAO+ phase influenced by a Hypsithermal period. The occurrence of the humid and relatively warm interval II is consistent with a negative phase in the NAO, as well as a relative restriction in ocean-Ría exchange. Interval III, which was drier and more productive, again suggests the dominance of a positive phase in the NAO, with a more intense oceanic connection and more energized upwelling.

[Pena, L., E. Calvo, I. Cacho, S. M. Eggins, and C. Pelejero, Identification and removal of Mn-Mg-rich contaminant phases on foraminiferal tests: Implications for Mg/Ca past temperature reconstructions, *Geochemistry, Geophysics, Geosystems*, 6, Q09P02, doi:10.1029/2005GC000930 \(2005\).](#)

The geochemical composition of foraminifera shells from an Ocean Drilling Program site in the Panama Basin has been analyzed by several analytical techniques (LA-ICP-MS, ICP-MS, XRD, SEM, EDX) in order to identify and evaluate the occurrence of contaminant phases which may bias paleoenvironmental reconstructions. LA-ICP-MS results on uncleaned tests indicate the presence of Mn-Mg-rich contaminant phases at the inner surfaces of the foraminiferal shells (which have Mn/Ca ratios up to 400 mmol mol⁻¹ and Mg/Ca ratios up to 50 mmol mol⁻¹). We have rigorously assessed the ability of different cleaning protocols to remove these contaminant phases and have obtained satisfactory results only when a reductive step is included. The analysis of cleaning residuals collected after each of the different cleaning steps applied reveals that high Mn values are associated with at least two different contaminant phases, of which only one is linked to high Mg values. XRD analysis further reveals that the Mn-Mg-rich phase is the Ca-Mn-Mg carbonate kutnahorite (Ca(Mn, Mg)(CO₃)₂). Our results demonstrate that the presence of kutnahorite-like minerals can bias Mg/Ca ratios toward higher values (by 7–36%) and lead to significant overestimation of past seawater temperatures (by 0.9 up to 6.2°C, in the case of these Panama Basin samples).

[Pelejero, C., E. Calvo, M. T. McCulloch, J. Marshall, M. K. Gagan, J. M. Lough, and B. N. Opdyke, Preindustrial to modern interdecadal variability in coral reef pH, *Science*, 309, 2204-2207 \(2005\).](#)

The oceans are becoming more acidic due to absorption of anthropogenic carbon dioxide from the atmosphere. The impact of ocean acidification on marine ecosystems is unclear, but it will likely depend on species adaptability and the rate of change of seawater pH relative to its natural variability. To constrain the natural variability in reef-water pH, we measured boron isotopic compositions in a ~300-year-old massive *Porites* coral from the southwestern Pacific. Large variations in pH are found over ~50-year cycles that covary with the Interdecadal Pacific Oscillation of ocean-atmosphere anomalies, suggesting that natural pH cycles can modulate the impact of ocean acidification on coral reef ecosystems.

[Pelejero, C., E. Calvo, T. T Barrows, G. A. Logan, and P. De Deckker, South Tasman Sea alkenone palaeothermometry over the last four glacial/interglacial cycles, *Marine Geology*, 230, 73-86 \(2006\).](#)

Alkenone palaeothermometry has demonstrated a wide spatial and temporal applicability for the reconstruction of sea-surface temperatures (SST). Some oceanic realms, however, remain poorly studied. We document UK37 index data for two sediment cores retrieved from the South Tasman Sea, one west of New Zealand (SO136-GC3) and the other southeast of Tasmania (FR1/94-GC3), extending back 280 kyr BP for the former and 460 kyr BP for the latter. High climatic sensitivity

on orbital time scales is observed at both locations, particularly west of New Zealand, where typical glacial/interglacial SST amplitudes always span more than 7°C. Southeast of Tasmania, SST amplitudes are lower in amplitude (4.3 to 6.9°C) with the exception of Termination IV, which involved a SST change over 8°C. The evolution of maximum glacial cooling through time is different at each location. Offshore New Zealand, maximum cooling during glacial stages increases with time, whereas south of Tasmania maximum cooling decreases with time. In addition, our data suggest heterogeneity in the spatial expression of SST during the penultimate and last glacial stages. These glacial periods are recorded differently in both areas, with Marine Isotopic Stage 6 being warmer than Marine Isotopic Stage 2 west of New Zealand, but slightly colder southeast of Tasmania. The area southwest of New Zealand appears susceptible to expansions and contractions of the Western Pacific Warm Pool and/or meridional migrations and changes in intensity of currents associated with the Tasman Front. The region southeast of Tasmania seems more sensitive to thermal changes as seen at high southern latitudes.

[Pelejero, C., E. Calvo, M. T. McCulloch, J. Marshall, M. K. Gagan, J. M. Lough, and B. N. Opdyke, Response to comment on “Preindustrial to modern interdecadal variability in coral reef pH”, *Science*, 314, 595c \(2006\).](#)

Coral reefs are exceptional environments where changes in calcification, photosynthesis, and respiration induce large temporal variations of pH. We argue that boron isotopic variations in corals provide a robust proxy for paleo-pH which, together with the likely concomitant changes in the reconstructed partial pressure of CO₂ (pCO₂) calculated by Mearns and McNeil, fall within ranges that are typical of modern coral reef ecosystems.

[Calvo, E., J. F. Marshall, C. Pelejero, M. T. McCulloch, M. K. Gagan, and J. M. Lough, Interdecadal climate variability in the Coral Sea since 1708 A.D., *Palaeogeography Palaeoclimatology Palaeoecology*, 248, 190-201 \(2007\).](#)

Low resolution (5-year) Sr/Ca and δ¹⁸O samples, extending back to 1708 A.D., were analysed from a *Porites* coral core collected from Flinders Reef, an offshore reef on the Queensland Plateau in the western Coral Sea (17.5°S, 148.3°E). Using the Sr/Ca ratio as a proxy for sea surface temperature (SST), we deconvolved a salinity record by subtracting the SST signal from the δ¹⁸O record. Decadal variability in the reconstructed salinity record is closely paralleled by changes in SST, with cooler (warmer) temperatures recorded during wetter (drier) periods. This relationship differs from the conventional view often described for tropical areas, where warm temperatures are associated with wet periods and cool temperatures with dry periods. The anticorrelation between reconstructed SST and salinity observed at Flinders Reef, however, matches the climatic effects expected from variations in the Interdecadal Pacific Oscillation (IPO), a recurrent pattern of SST variability over the Pacific Ocean which is known to modulate Australia's climate, in particular the impact of ENSO events on decadal time scales. On longer timescales, salinity seems to have remained almost constant for the last two centuries after a progressive freshening of surface waters that culminated around 1800 A.D. Conversely, SSTs show a warming trend towards the late 20th century.

[Barrows, T.T., S. Juggins, P. De Deckker, E. Calvo, and C. Pelejero, Long-term sea surface temperature and climate change in the Australian-New Zealand region, *Paleoceanography*, 22, PA2215, doi:10.1029/2006PA001328 \(2007\).](#)

We compile and compare data for the last 150,000 years from four deep-sea cores in the midlatitude zone of the Southern Hemisphere. We recalculate sea surface temperature estimates derived from foraminifera and compare these with estimates derived from alkenones and magnesium/calcium ratios in foraminiferal carbonate and with accompanying sedimentological and pollen records on a common absolute timescale. Using a stack of the highest-resolution records, we find that first-order climate change occurs in concert with changes in insolation in the Northern Hemisphere. Glacier extent and inferred vegetation changes in Australia and New Zealand vary in tandem with sea surface temperatures, signifying close links between oceanic and terrestrial temperature. In the Southern Ocean, rapid temperature change of the order of 6°C occurs within a few centuries and appears to have played an important role in midlatitude climate change. Sea surface temperature changes over longer periods closely match proxy temperature records from Antarctic ice cores. Warm events correlate with Antarctic events A1–A4 and appear to occur just before Dansgaard-Oeschger events 8, 12, 14, and 17 in Greenland.

[Calvo, E., C. Pelejero, P. De Deckker, and G. A. Logan, Antarctic deglacial pattern in a 30 kyr record of sea surface temperature offshore South Australia, *Geophysical Research Letters*, \(in press\).](#)

Comparison of ice cores from Greenland and Antarctica shows an asynchronous two-step warming at these high latitudes during the Last Termination. However, the question whether this asynchrony extends to lower latitudes is unclear mainly

due to the scarcity of paleorecords from the Southern Hemisphere. New data from a marine core collected off South Australia (~36°S) allows a detailed reconstruction of sea-surface temperatures over the Last Termination. This confirms the existence of an Antarctic-type deglacial pattern and shows no indication of cooling associated with the Northern Hemisphere YD event. The SST record also provides a new comparison with the more extensive paleoclimatic data available from continental Australia. This shows a strong climatic link between onshore and offshore records for Australia and to Southern Hemisphere paleorecords. We also show a progressive SST drop over the last ~6.5 kyr not seen before for the Australian region.