

New Wave

New challenges in internal wave dynamics 2015

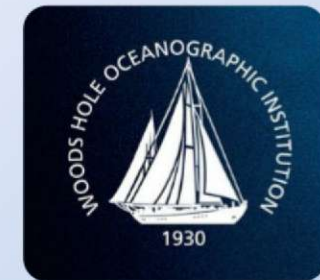
Large-scale atmospheric gravity waves in the Red Sea: SAR contributions to an unfolding mystery

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- Loughborough university
- Woods Hole Oceanographic Institution

Preview

Internal waves in the Red Sea: a satellite view

Motivations:
why study internal waves?
why here?

SAR:
seeing waves from space?

Red Sea:
a hotspot for internal waves



Seeing Internal Waves from space...



As far as physics is concerned, water and air are very similar.

Just like a regular packet of oceanic internal waves, solitary waves can also propagate in the atmosphere.

And if we saw them **up-close** they would look very much like this...

Note the condensation and cloud formation in the ascending branches.

Seeing Internal Waves from space...

Despite being a bit counterintuitive, atmospheric gravity waves (AGWs) can be imaged by space borne sensors.

In particular by SAR:



Low orbit sun-synchronous satellites

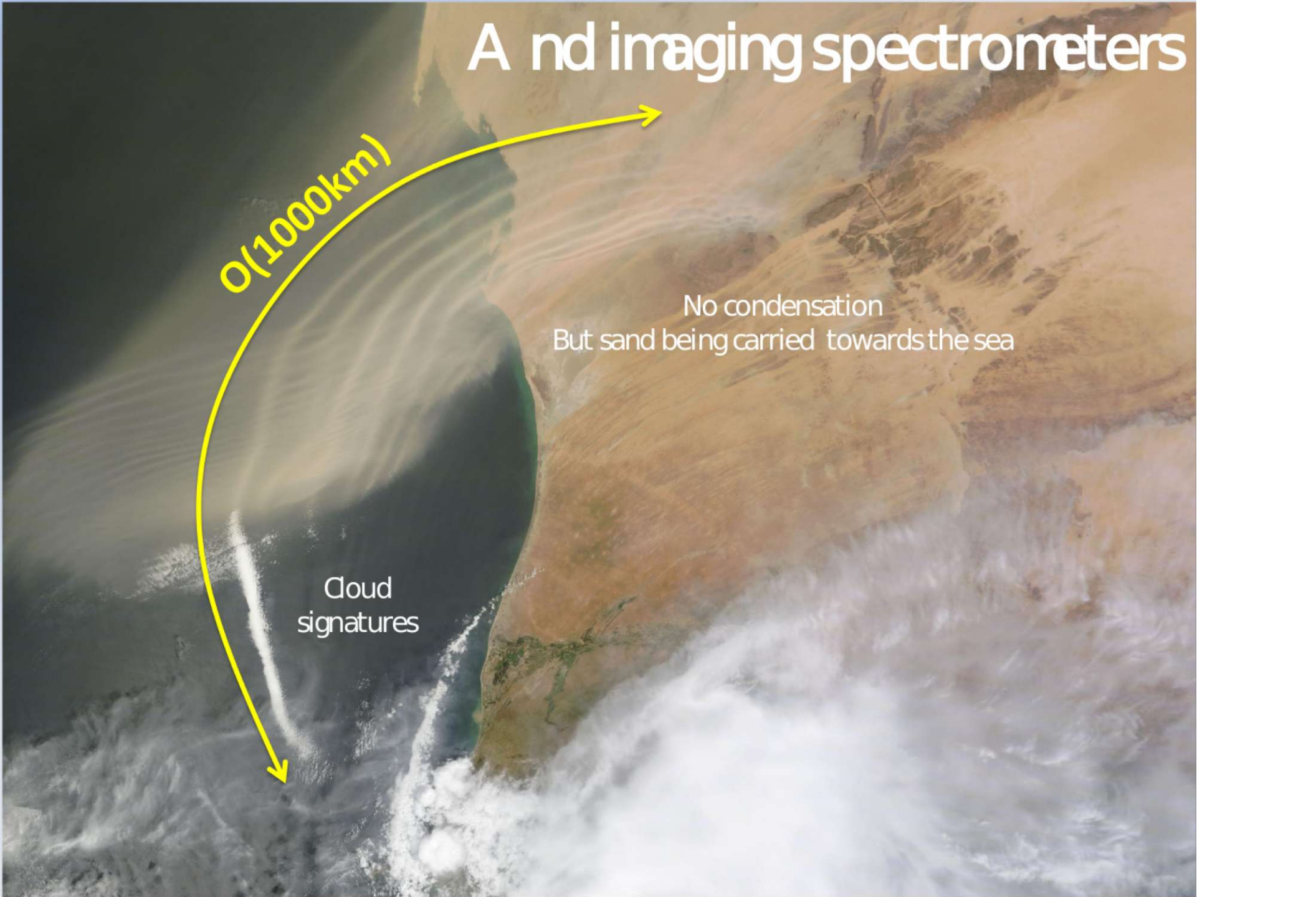


A nd imaging spectrometers

$O(10000\text{km})$

No condensation
But sand being carried towards the sea

Cloud
signatures





Red Sea AGWs: motivations

Academic subject vs. real world features



Intrinsically turbulent structures.

Prone to mixing and transport.

Significant vertical oscillations and strong winds.

Hazard for low altitude aircrafts, take-off and landing (Christie and Muirhead, 1983). Clear air turbulence.

By the way, they often propagate in the lower troposphere, and are used for surfing ...

surf?!

Morning Glories
(AUSTRALIA)



Red Sea: a region for 'exotic' A G W observations



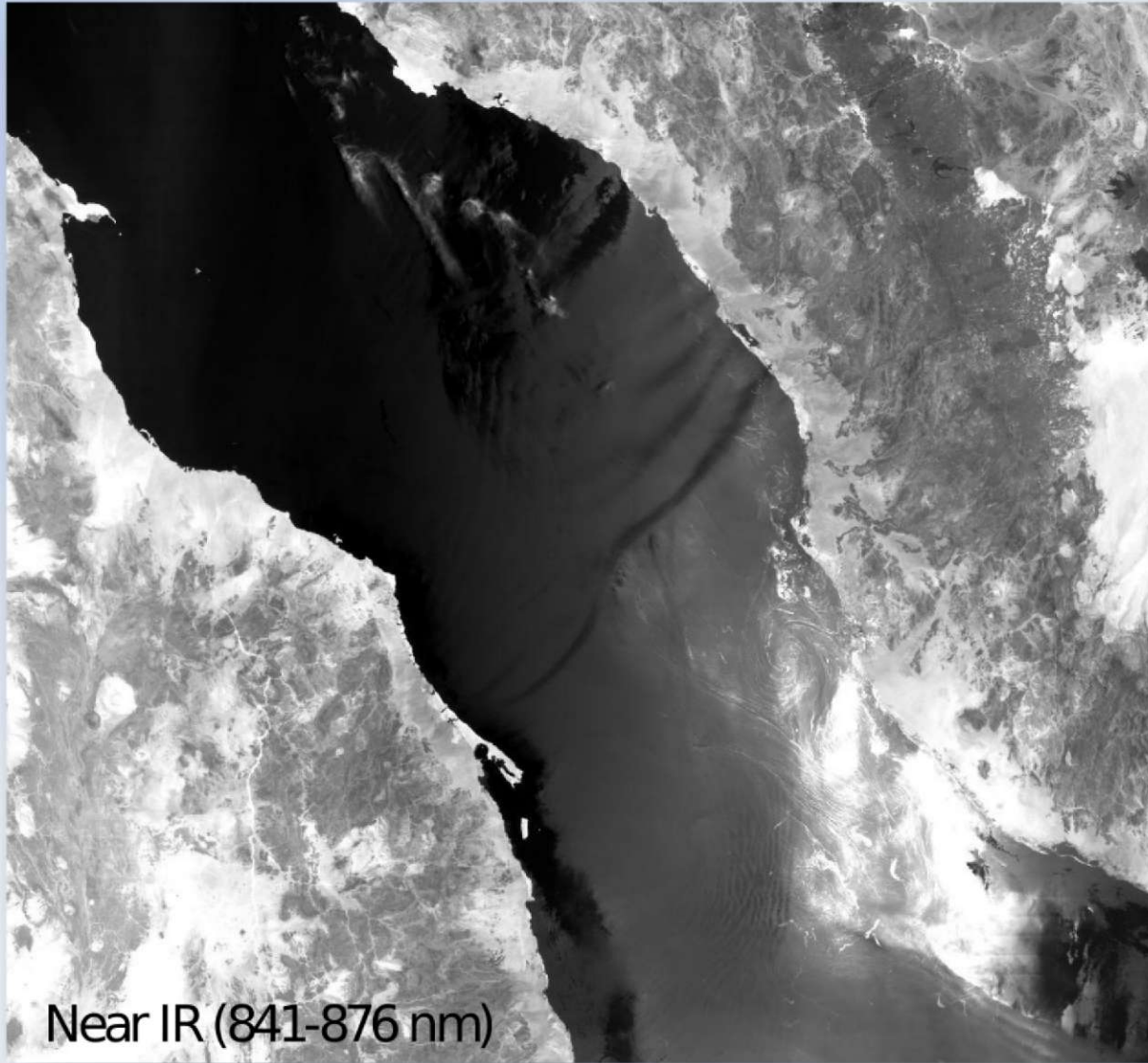
Red Sea overview from the international space station

A satellite image of the Red Sea region. The sea is a dark blue color, and the surrounding land is a light brown/tan color. A white dot is located on the northern coast of the Red Sea, marking the location of Jeddah airport. The text "Jeddah airport" is written in white next to the dot. In the bottom left corner, there is white text that reads "Frequently observed sand storms and AGWs".

Jeddah
airport

Frequently
observed sand
storms and AGWs

Red Sea: SAR view of an AGW hotspot



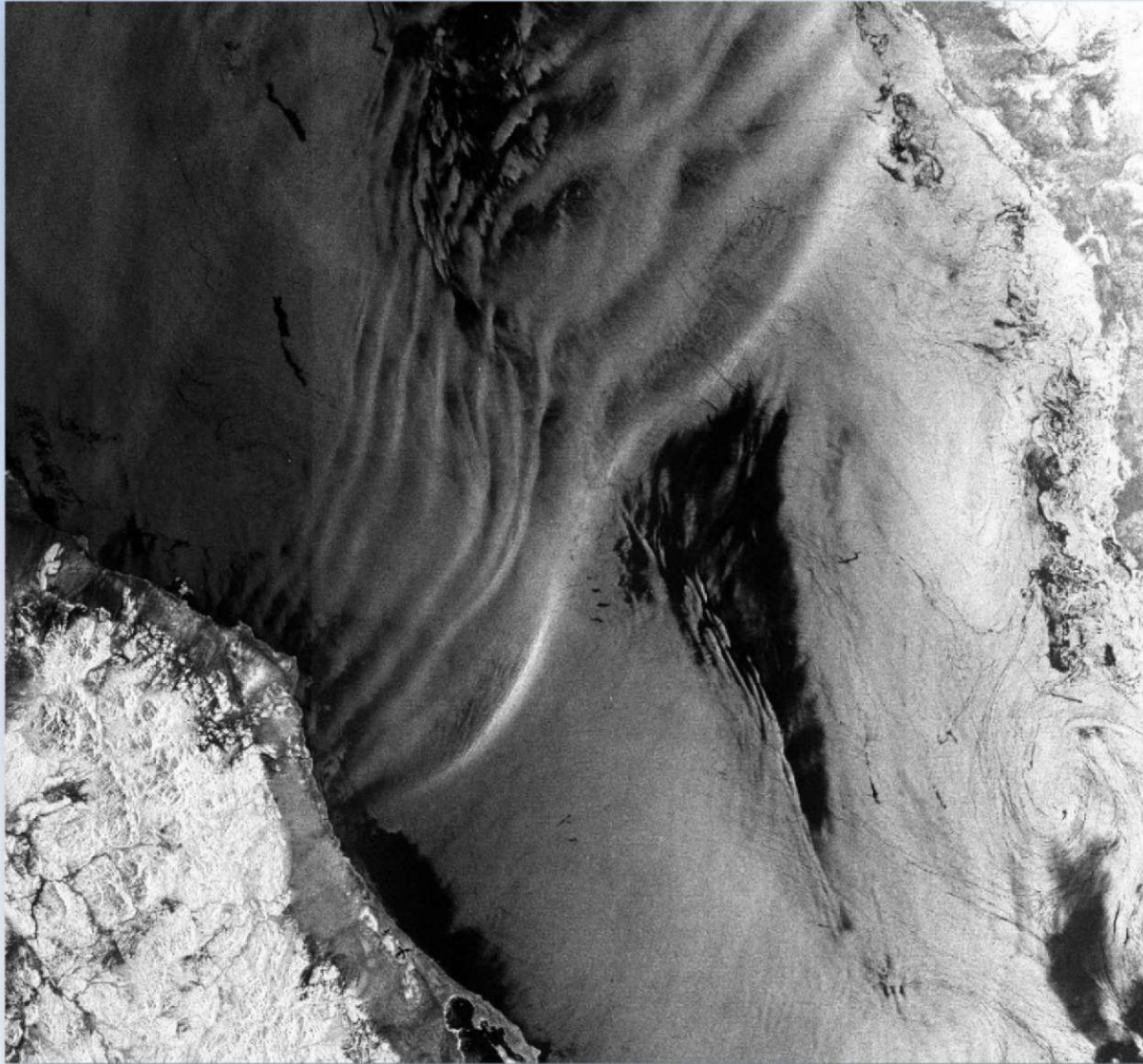
MODIS-Terra at 8h12m,
11 May 2004

Extending from the SE
to the NW for some 200
km - full width of the
Red Sea.

No apparent cloud
formation.

Near IR (841-876 nm)

Red Sea: SAR view of an AGW hotspot

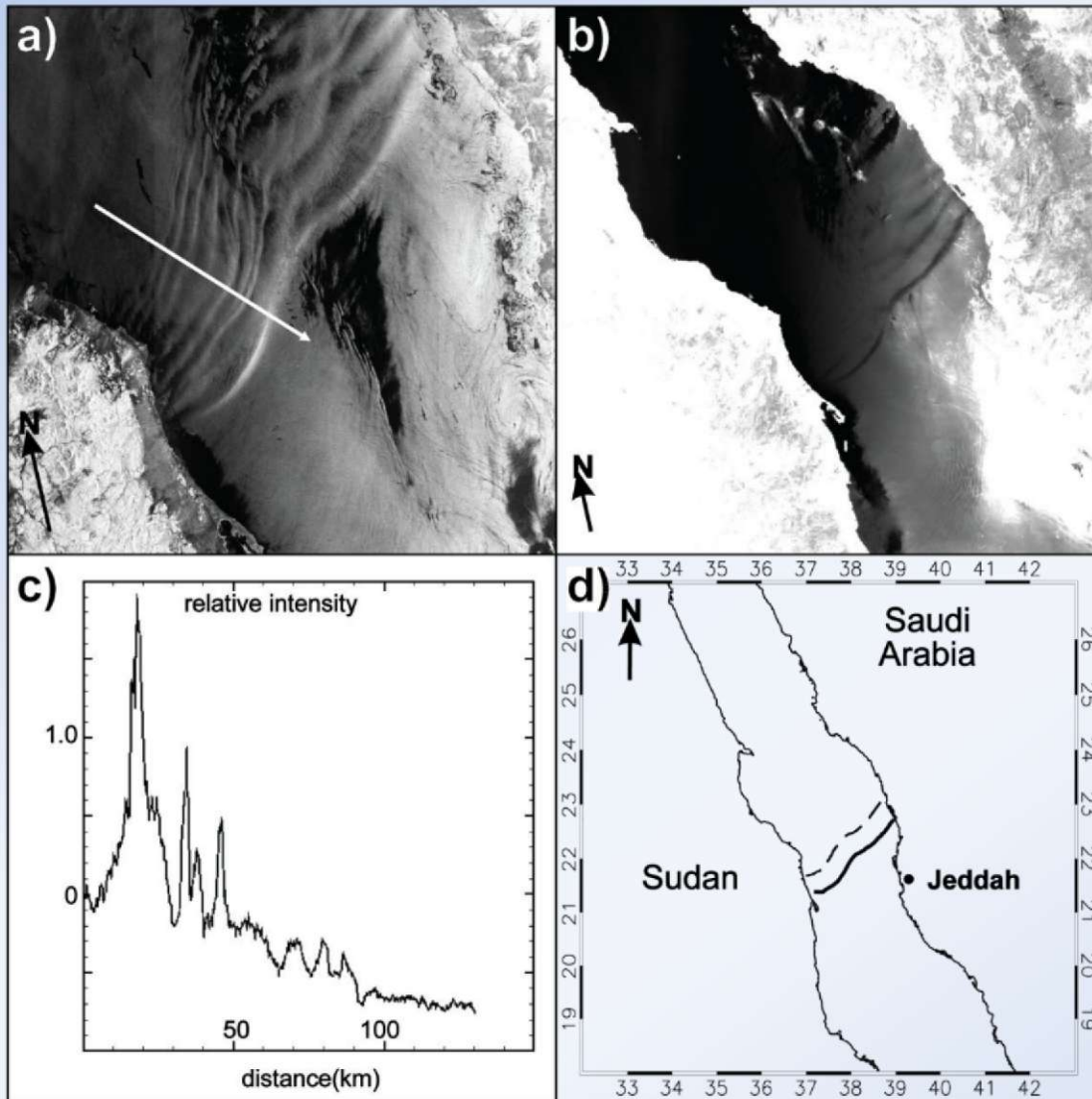


Envisat-ASAR at 7h26m,
11 May 2004

i.e. some 46 minutes earlier.

Typical rank-ordered packet-like structure can be clearly seen across the Red Sea.

Red Sea: A GW hotspot



Synergetic view – some sense of motion

Composite view:

Propagation is close to 130°T .

At least **7 individual waves** can be seen in the transect in panel (c), where the rank structure is also clearly seen.

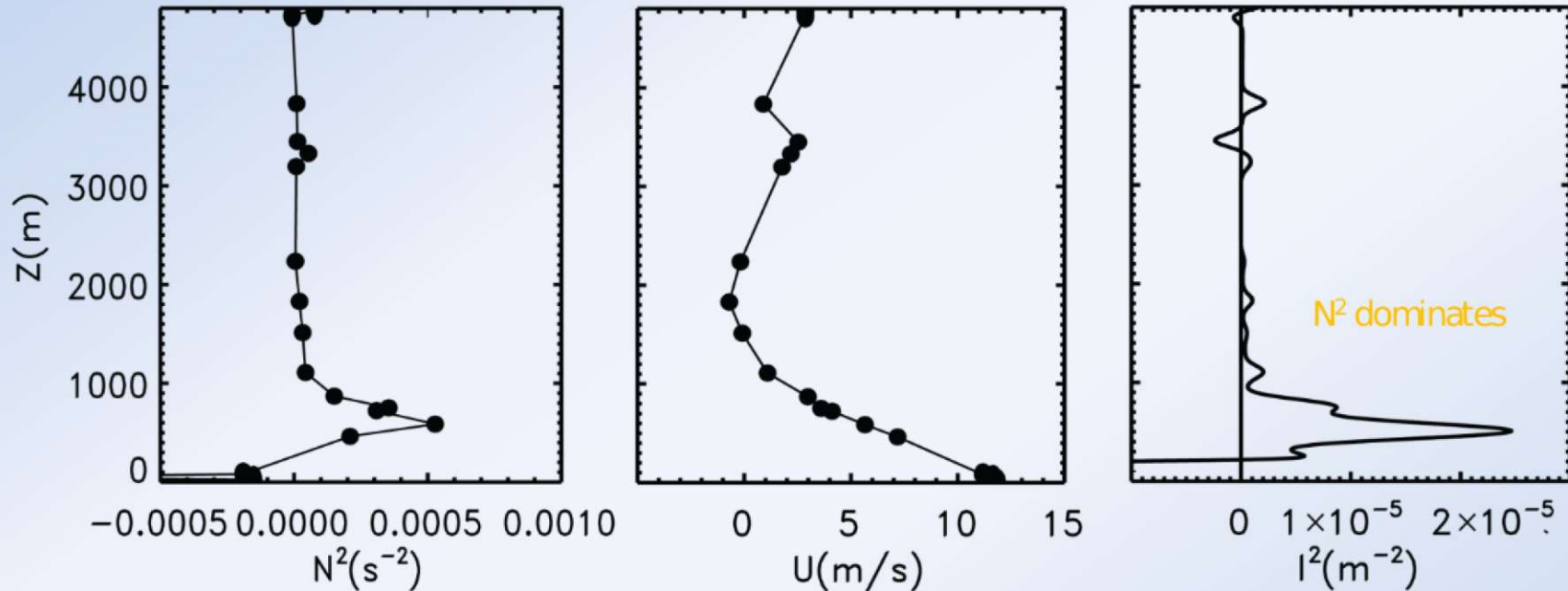
Characteristic length-scale for individual waves is between **2-8 km**.

Average propagation speeds around **15 m/s**.

Red Sea: A GW hotspot

It is essential to get a view of the atmosphere's vertical structure

Taken at Jeddah airport at 9h00m UTC - less than hour after MODIS image



Taylor- Goldstein equation:

$$d^2 w / dz^2 + (\rho - k^2) w = 0; \quad \rho = N^2 / (U - c)^2 - U'' / (U - c)$$

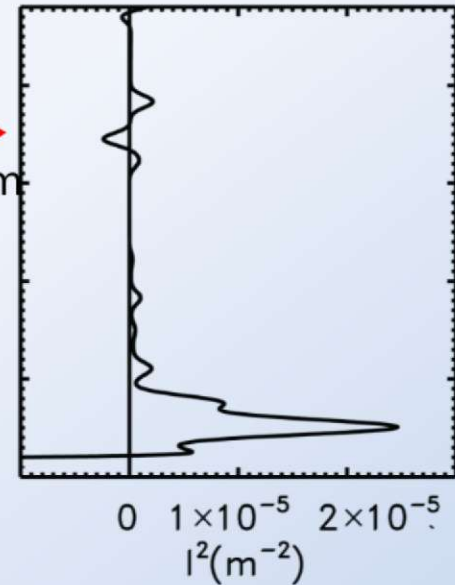
i.e. $l^2 \gg k^2$ means suitable waveguide in the lower troposphere

Red Sea: A GW hotspot

Solving the Taylor-Goldstein equation means having the vertical modal structure - e.g. $w(z)$

Having the vertical modal structure means we can use weakly nonlinear long-wave theory

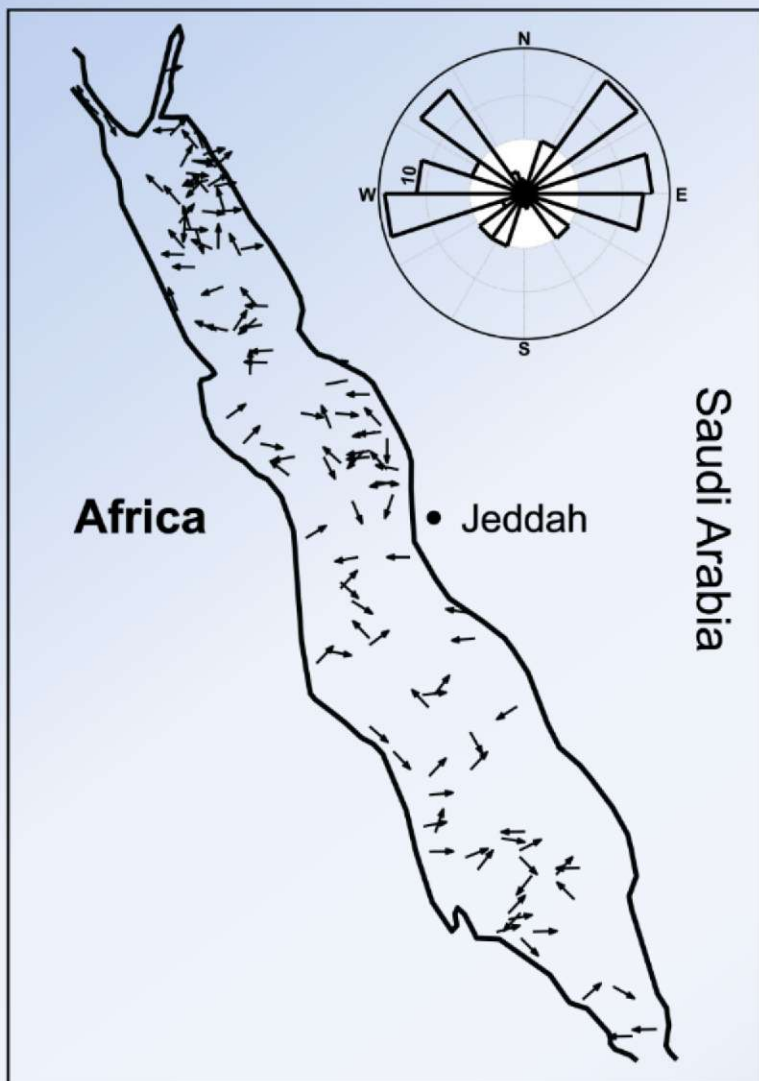
	KdV	BDO
Upper boundary	$\phi = 0$ at $H = 3000$ m	$\phi_z = 0$ at $d = 1300$ m
C_{linear} (m s^{-1})	14.4	15.4
I	0.0476	0.0372
δ	3.9023×10^6	6.2365×10^3
μ	0.0164	0.0280
V (m s^{-1})	15.0	16.9
Amplitude (m)	114	178



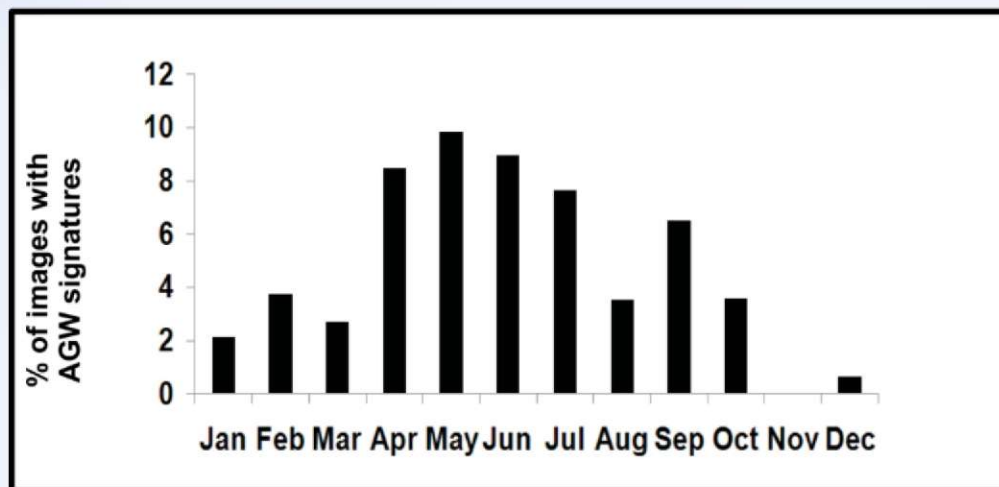
$$V-c = \mu a / 3 = 4\delta \lambda^2, \lambda \text{ being the characteristic width of the solitary wave}$$

Amplitudes are of the order of hundreds of meters, and WNL theory may be underestimating amplitudes - very sensitive to λ and waveguide boundaries.

Red Sea: A G W hotspot



How frequent are these waves?



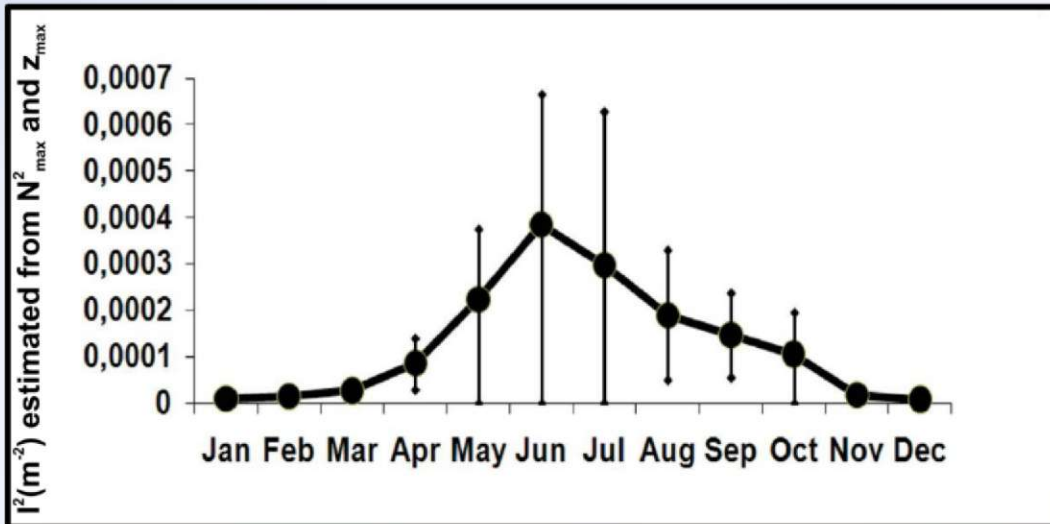
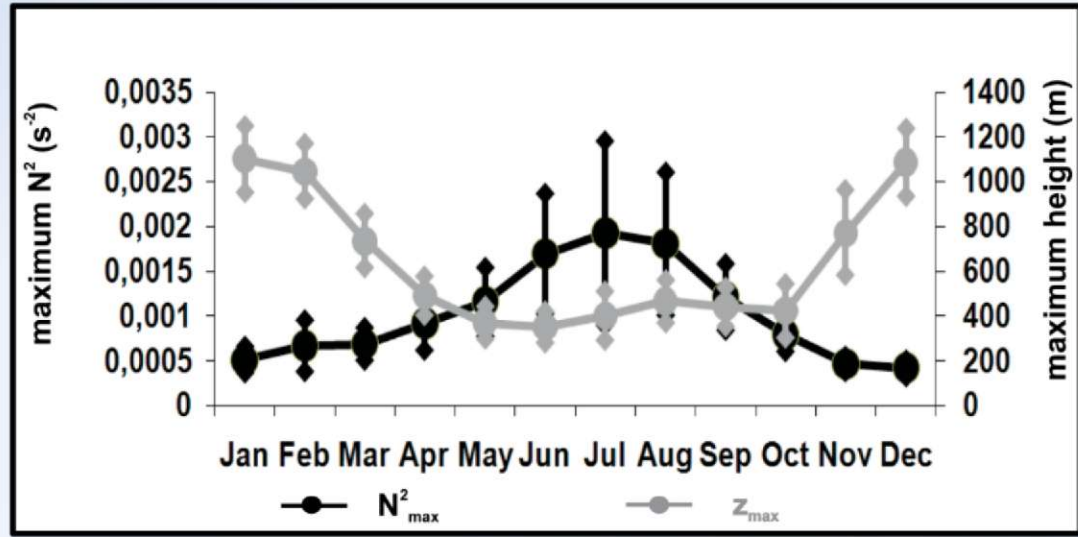
Very frequent and scattered over the entire red sea, after having seen close to 100 SAR images.

More so, between April and September.

Is there a reason for that?

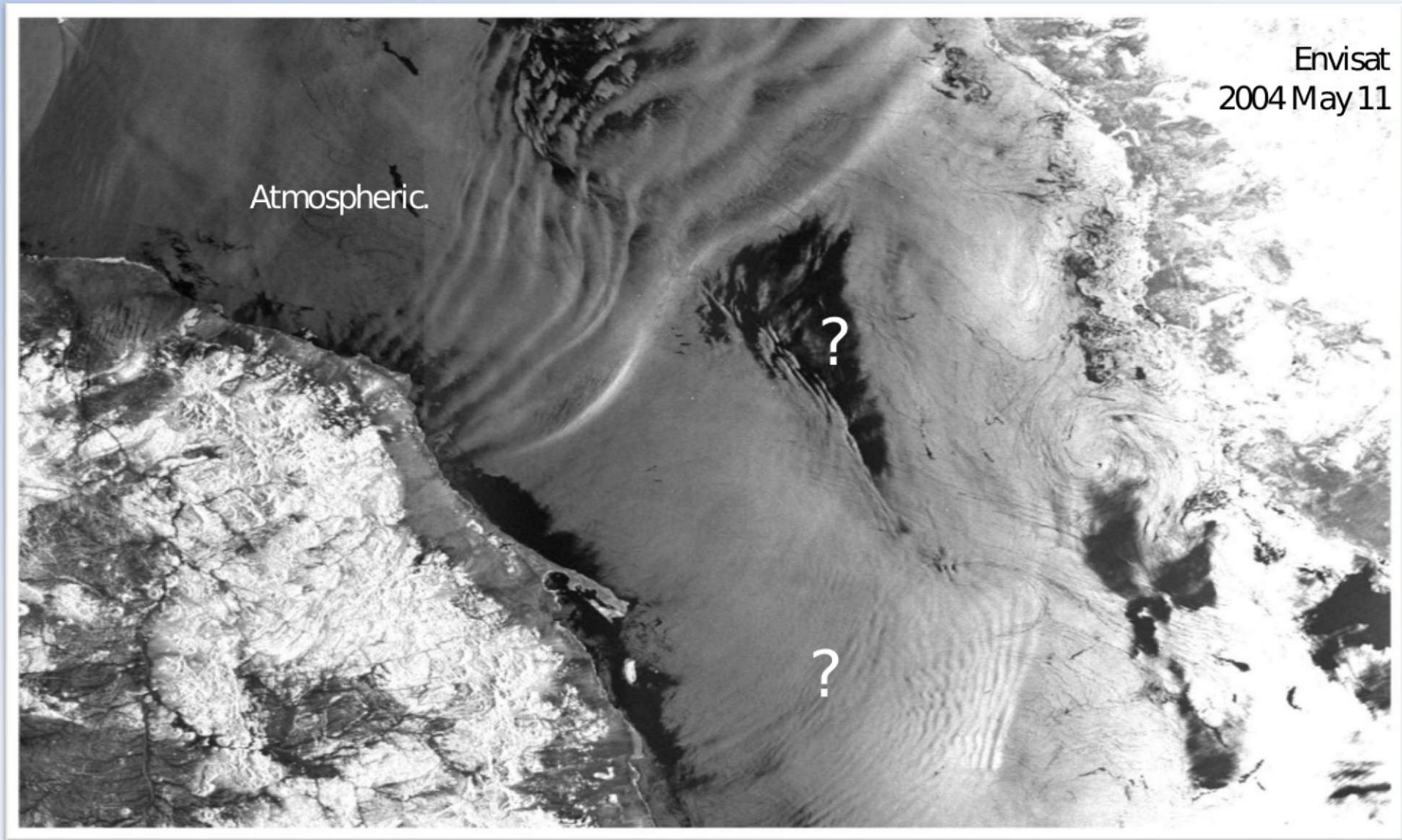
Red Sea: A G W hotspot

Maybe there is... The atmosphere's stability appears to increase and become shallower at the same time - from daily soundings taken over for more than 10 years at Jeddah.



Since N^2 dominates in the Scorer parameter, the overall effect seems to be that of increased waveguide conditions.

Beware of look-alikes



Distinction between atmospheric and oceanic ISWs may be an issue. Several mishaps have in fact occurred in the literature. See e.g. Alpers and Huang (2011). Check out more at <http://jmagalhae0.wix.com/internal-waves>

Conclusions

- Remote Sensing has shown the Red Sea to be a hotspot for atmospheric large-scale internal waves;
- Remote sensing provides unique contributions to determine ground-truth AGW characteristics;
- But many aspects remain allusive – more research is needed. Modelling and in situ efforts need to be called in.

Thank you all!